AN AUTOMATED COMPUTERIZED SYSTEM FOR TESTING THE UNIFORMITY OF AGRICULTURAL SPRAY NOZZLE PATTERNS

Submitted to

The Engineering Honors Committee
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Dear Honors Committee:

I am pleased to submit this analysis of a new method for nozzle spray pattern testing and some test results obtained using this system.

This report consists of recommending an alternative nozzle pattern testing system, that would be both automated and more efficient. The basis for the recommendation comes from the results of several analyses of criteria I established for a feasible system. The proposed system will collect data faster than the current system while maintaining a relatively low cost.

Several tests have already been conducted with the system and the results of these tests are also included. The research included testing a wide variety of nozzle types for the effects of wear on the spray pattern uniformity.

Respectfully submitted,

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ACKNOWLEDGMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Background

Pesticides play an important role in crop production today. The popularity of pesticides is evident from the 170 percent increase in the total amount of farm pesticide consumption between the years of 1964 and 1982, while the total amount of land under cultivation remained relatively constant (Wiles, 1989). Ever since their introduction into the United States during the 1940s, pesticides have continually increased per acre yields and overall agricultural production. These increases are brought about by controlling pests, such as, weeds and insects. Weeds can block sunlight and use water which could otherwise be used by the agricultural crop. Insects can damage the crop in several different ways, but especially by eating the foliage.

Pests in agricultural crops are most commonly controlled by pesticides in the form of sprays. These sprays are most effective when they are applied uniformly and at the proper rate (Doll et al., 1966; Reed and Ferrazza, 1984; Hall, 1987; Hislop, 1987). The directions on a pesticide container label indicate the recommended practices for best results. Misapplication has been reported to cost U.S. farmers as much as a billion dollars per year (Reichenberger, 1980). Calibration clinics in Ohio revealed that more than one-third of the sprayers surveyed were overapplying chemicals mostly because of worn nozzles (Ozkan, 1987).

Spray nozzles, although they are one of the least expensive components of a spraying system, have the most pronounced effect on achieving optimum application. The shape and size of the opening or orifice of a nozzle controls the amount of liquid applied, the size of the spray droplets, and the uniformity of the pattern that leaves the nozzle. Over a period of time the corrosive chemicals, high pressure forces, and insoluble abrasive particles that pass through the nozzles, can cause undesirable wear. This wear may eventually cause the nozzles to attain different characteristics than those for which they were designed. Because these spray nozzles are such a critical component in the spraying system, many researchers have studied these spray nozzles and their wearing characteristics.

Most known research conducted on nozzle wear (Friesen, 1984; Menzies et al.,1976; Novak and Cavaletto, 1988; Pearson and Fry, 1984; Reed and Ferrazza, 1984; and Reichard et al., 1991) has concentrated only on the change in flow rate. However, the uniformity of spray across the application area is as important in achieving satisfactory pest control as the amount of pesticide required. Little research has been conducted on the many different spray pattern characteristics that depend on the specific nozzle or how this pattern changes as the nozzle wears. Changes in the spray pattern as a result of nozzle wear may result in excessive overlapping, or in untreated spots between adjacent nozzles. Excessive overlapping may cause a reduction in crop yield, because the plants may be exposed to higher doses of pesticides than they can tolerate. Excess pesticide also increases the potential risk of contaminating nearby water resources. On the other hand, the untreated spots will allow pests to inhabit the area and damage the crop.

Although some researchers (Doll et al., 1966; Friesen, 1984; Reed and Ferrazza, 1984) investigated the effects of wear on spray pattern uniformity, the results have been highly inconsistent. This is mostly due to different procedures followed by the researchers. Moreover, the current standards on nozzle wear (ASTM Standards E641) do not adequately include all the variables that play an important role in the effects of wear on nozzle spray patterns. An effort should be made to obtain a more thorough set of standards so that the efforts of all nozzle wear researchers can be coordinated to provide easier comparison of test results.

To obtain a more complete standard for nozzle wear testing all the relevant variables that effect this process should be investigated. One such variable is the various types of nozzles available for agricultural use. Agricultural spray nozzles are designed with many different orifice sizes and shapes. Each type of nozzle has a distinct orifice design that will generate a specific spray pattern. Nozzles are also made from a variety of materials (e.g. steel, plastic, brass, and nylon) which have different wear characteristics. The relative position of the nozzles will have a significant effect on spray pattern uniformity as well. The recommended relative position of the nozzles varies depending on the type of nozzle used.

The lack of data on nozzle wear as it effects spray distributions can be attributed to the inadequacy of current methods for testing nozzle spray patterns. There are several types of spray pattern analysis systems (commonly referred to as patternators) currently being implemented. Most of these patternators are based on gathering volume data from graduated cylinders as illustrated in Figure 1. With these systems a spray nozzle is mounted above a tilted and corrugated table. As the nozzle sprays liquid, its spray pattern is divided into the corrugations and the liquid runs off the edge of the table into the graduated cylinders. Next, the data corresponding to the level of liquid in each of these graduated cylinders must be read manually and then analyzed. This method is time consuming, can give imprecise measurements, and increases the chances of encountering error during recording and analyzing the data. Therefore, a more efficient and accurate system for collecting spray pattern data is needed.

Several researchers have constructed new patternator systems that collect and analyze the data more efficiently. One researcher utilized a digital micrometer to measure the height of corks floating in the glass cylinders (Grisso, 1991). One of the nozzle manufacturers has implemented an imaging system which sends a photograph of the water height in the cylinders to a computer (Hallman, 1991). Another nozzle manufacturer has two types of patternators (Andersen and Drouin, 1991). One of them has a weight transducer at the bottom of each glass cylinder. Once a maximum reading in one cylinder is achieved the weights from all cylinders

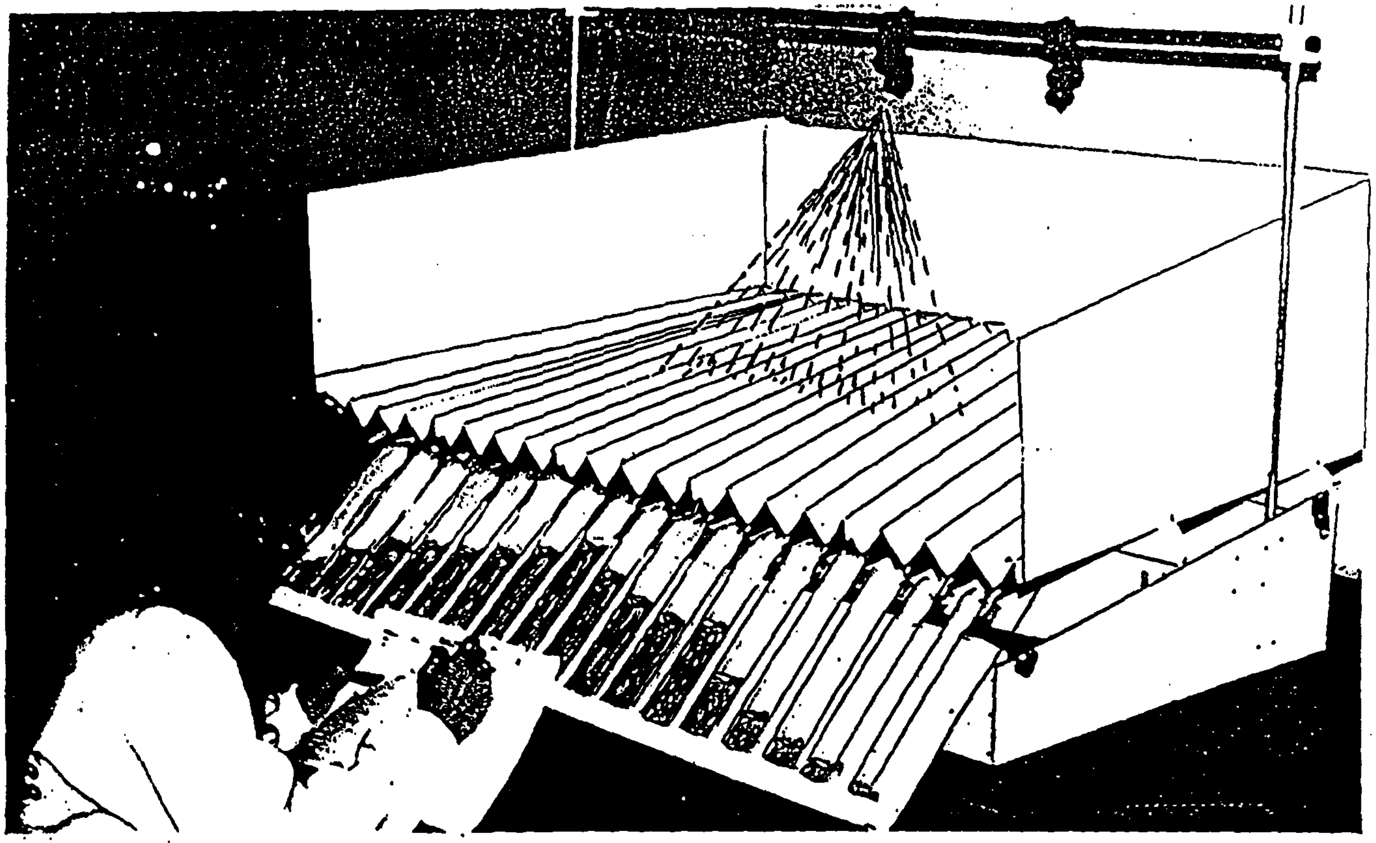


Figure 1. Manual spray nozzle paternator with graduated tubes.

are sent to a computer. The other system they have uses a single top loading balance mounted on a carriage which moves along under the glass cylinders and stops to measure the weight in each one. For each of these systems the data from the measuring devices are sent directly to a computer. This eliminates the error due to human intervention, saves time because the data need not be entered by hand, and minimizes the amount of manual labor required.

However, these systems still have some problems. One such problem is cost (many cost well over $10,000 and as much as $100,000). Another problem is that it takes up to 10 minutes to gather data for one nozzle test.

An automated system that has a more efficient method of data collection, a lower cost, an adequate repeatability, and an acceptable accuracy, as compared to current systems, would be a welcome improvement. Along with these criteria the system should retain some of the characteristics of the conventional patternator, including: capability to test all types of nozzles in normally mounted positions and not interfere with the spray pattern before the data is collected.

Once an improved system has been developed it can be used to obtain the previously mentioned standards for nozzle wear testing. These standards would help to coordinate the efforts of this research, so that results can be compared accurately with those acquired by other researchers. However, before a set of standards can be reached, more research is needed to quantify the effects of the various variables that are involved in these tests.

OBJECTIVES

The specific objectives of this project are as follows:

1. To develop an automated spray nozzle testing system.
2. To test this automated system for repeatability, efficiency, and accuracy.
3. To investigate the changes in spray patterns of worn flat fan spray nozzles of varying capacities and materials.

EQUIPMENT

There are two separate systems involved in the nozzle testing process. The first is the new automated patternator system and the other is the system used for wearing the nozzles.

Automated Patternator System

A new automated patternator was developed based on the concept used in designing a similar automated system (Carpenter et al., 1988). The system Carpenter et al. developed moved a spraying nozzle over the top of a stationary electronic top loading balance. Because of several difficulties with vibration and spray impact force, they decided not to further develop this system. The new system designed for this study has many similar features to this other patternator and to most currently used conventional patternators (see Figure 2). One similarity is that they all have a system that pumps liquid through one or more nozzles mounted above a tilted and corrugated table.

The spraying system consists of a motor, a pump, a supply tank, hoses, a pressure regulator, filters, pressure gauges, a spray boom, and nozzles. A 0.56 kW (3/4 hp) electric motor located under the table drives the pump that moves the water through the system. A 61 by 45.7 by 45.7 cm (24 by 18 by 18 in.) rectangular storage tank also positioned beneath the table is partially filled with water. The water in the tank is continually recycled to be sprayed through the nozzle. The pressure regulator is used to adjust the water pressure at which the nozzles are operating. The

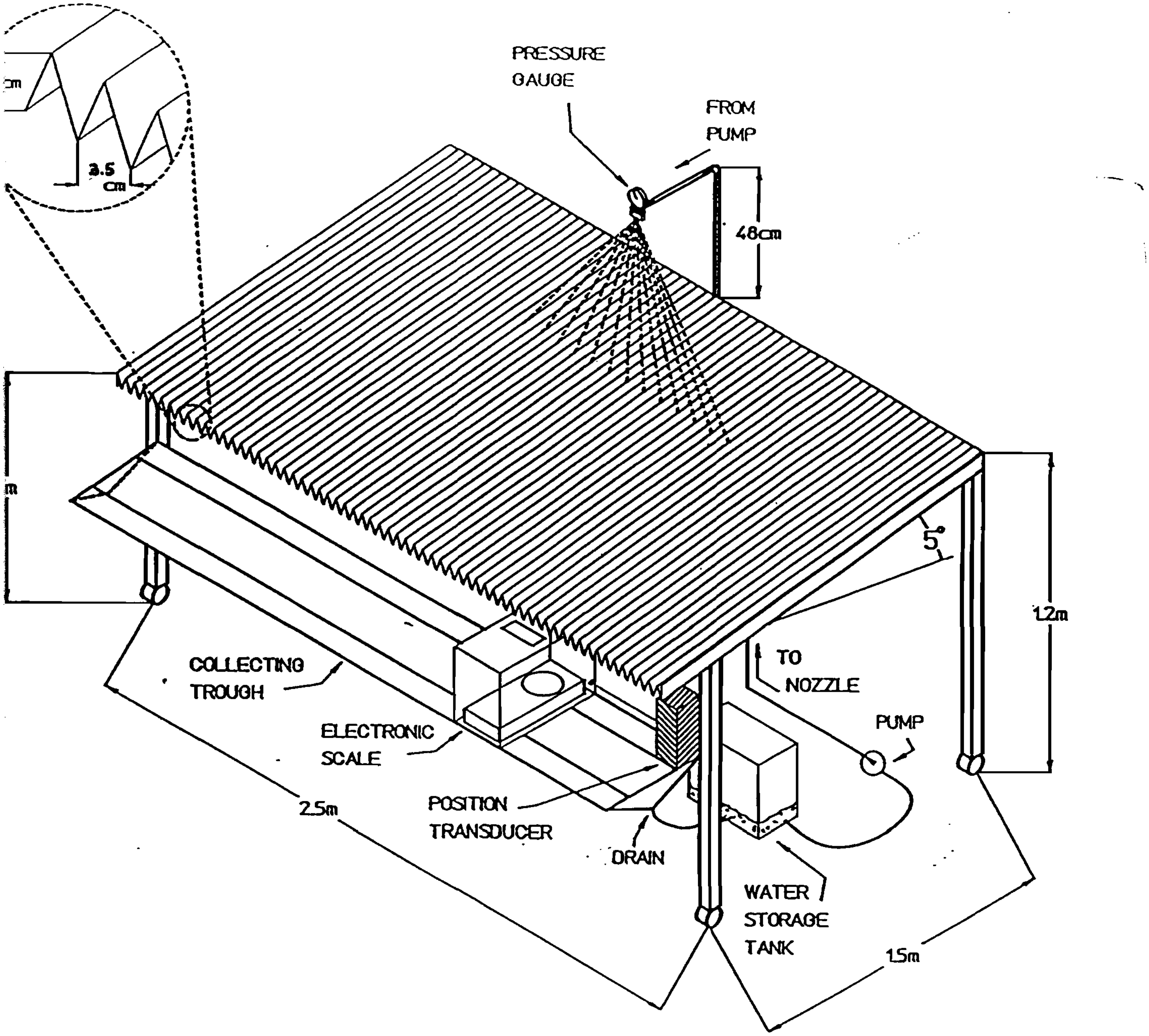


Figure 2. Automated spray nozzle patternator system.

water must also pass through several filters before reaching the nozzle orifice. This is to prevent large particles from plugging or damaging the nozzles. Five nozzles are mounted on a 1.27 cm (0.5 in.) pipe boom located above the table. Although the boom height is adjustable, most of the tests were conducted at about 48.3 cm (19 in.). This height is within the range of nozzle manufacturers recommended heights for 80° flat fan nozzles. Only the center nozzle located 54 cm (21.25 in.) from either of the two pressure gauges, was used for these tests.

The V-shaped corrugations on the surface of the table are 5 cm (2 in.) deep and 3.5 cm (1.4 in.) wide (from peak to peak) to keep the liquid from splashing out and into adjacent channels. The table top is tilted 5 degrees to direct the liquid into either the collection devices or the collection trough located beneath the lower edge of the table.

The main difference between the new automated system and the other systems is in the collection and measurement of the liquid discharged from the patternator. Instead of using numerous graduated cylinders, the automated system utilizes a single collection unit which sends data directly to a computer as it moves across the end of the table.

The collection unit is mainly a container sitting on an electronic top-loading balance (Mettler PM2000), which has an accuracy of $\pm$ 0.01 gram. The container and balance are enclosed by a plexiglass housing except for a narrow 7.6 by 10.4 cm (3 by 4.1 in.) slot in the top. This housing prevents spray that is not collected by the container from interfering with measurements. The spray liquid from two or three corrugations at a time can enter the housing through the narrow slot and deposit into the container. Liquid discharged from the remaining channels enters the collection trough and is returned to the supply tank.

A few modifications produced a better design of the driving and guidance systems for the collection unit. The unit is mounted on two tubular collars that guide it along a double bar track which is located beneath the lower edge of the tilted table top. The unit was originally driven by a roller chain and sprocket assembly (see Figure 3). As a result of problems with vibration and varying drive speed, the drive system was modified. This was accomplished by replacing the final chain drive with a much lighter cable and pulley system. The tightly stretched cable pulls the collection unit from a point located between the two guide bars to eliminate the moments created by pulling the unit from any other point. These moments were thought to have caused an increased frictional force between the track and the collars in the original design. This is because the final chain drive pulled the unit at a point far from the center.

In the final design, the original chain and sprocket system is still used as a transmission to reduce the drive speed from a 0.37 kW (1/4 hp) electric motor (Dayton 4Z248B). This transmission passes the reduced speed on to the final drive cable. The drive system moves the collection unit from left to right at a constant 3.5 cm/s (1.4 in./s) velocity during most tests. Because of this

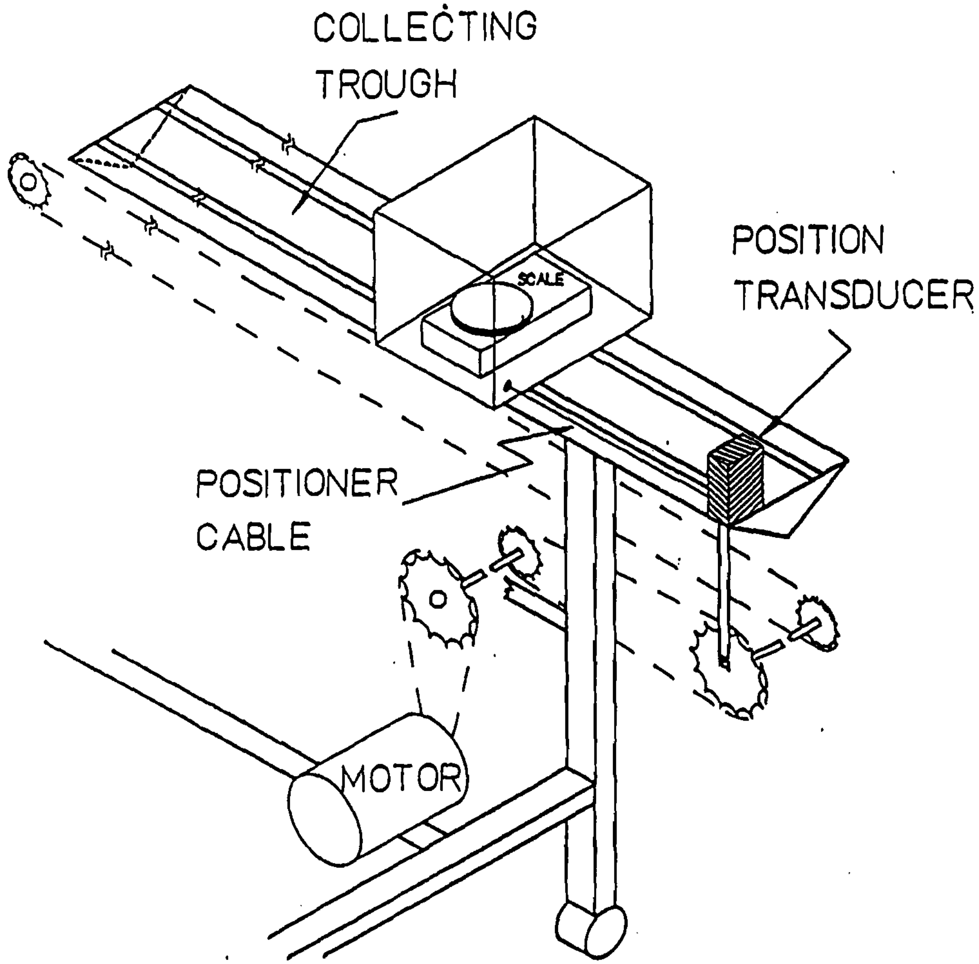


Figure 3. Data collection unit and chain and sprocket drive assembly for the automated patternator of figure 2.

constant velocity, the balance collects spray liquid for the same amount of time from each of the corrugations. This is necessary for achieving accurate results. The speed of the electric motor can be adjusted by a variable power supply (Dayton). This ultimately allows the user to adjust the travel speed of the collection unit.

Along with the weight data a position is recorded corresponding to the location where this data is obtained. This task is accomplished by using an analog position transducer (MagnaTek, model PT-150A) attached to the collection unit by a small cable. The position and weight data are then sent through cables to a 5150 IBM AT computer at a rate of 7 times per second. The digital weight signal is sent via an RS232 cable directly into the computer through a serial port. Since the position data is an analog signal, it is sent to the computer through an analog-to-digital board (Analog Devices, model RTI-820), that is mounted in one of the computer's expansion slots. This data is sent to a scientific software package called ASYST. A computer program was written in the ASYST language to collect, analyze, and store the data. The procedures for this software program and the nozzle tests in general are explained later. A listing of the program is given in Appendix B.

Nozzle Wear Test Stand

The method for wearing the nozzles consists of passing a liquid, containing an abrasive wearing agent, through the nozzles. A new system (Figure 4) was constructed by Reichard et al. (1991)

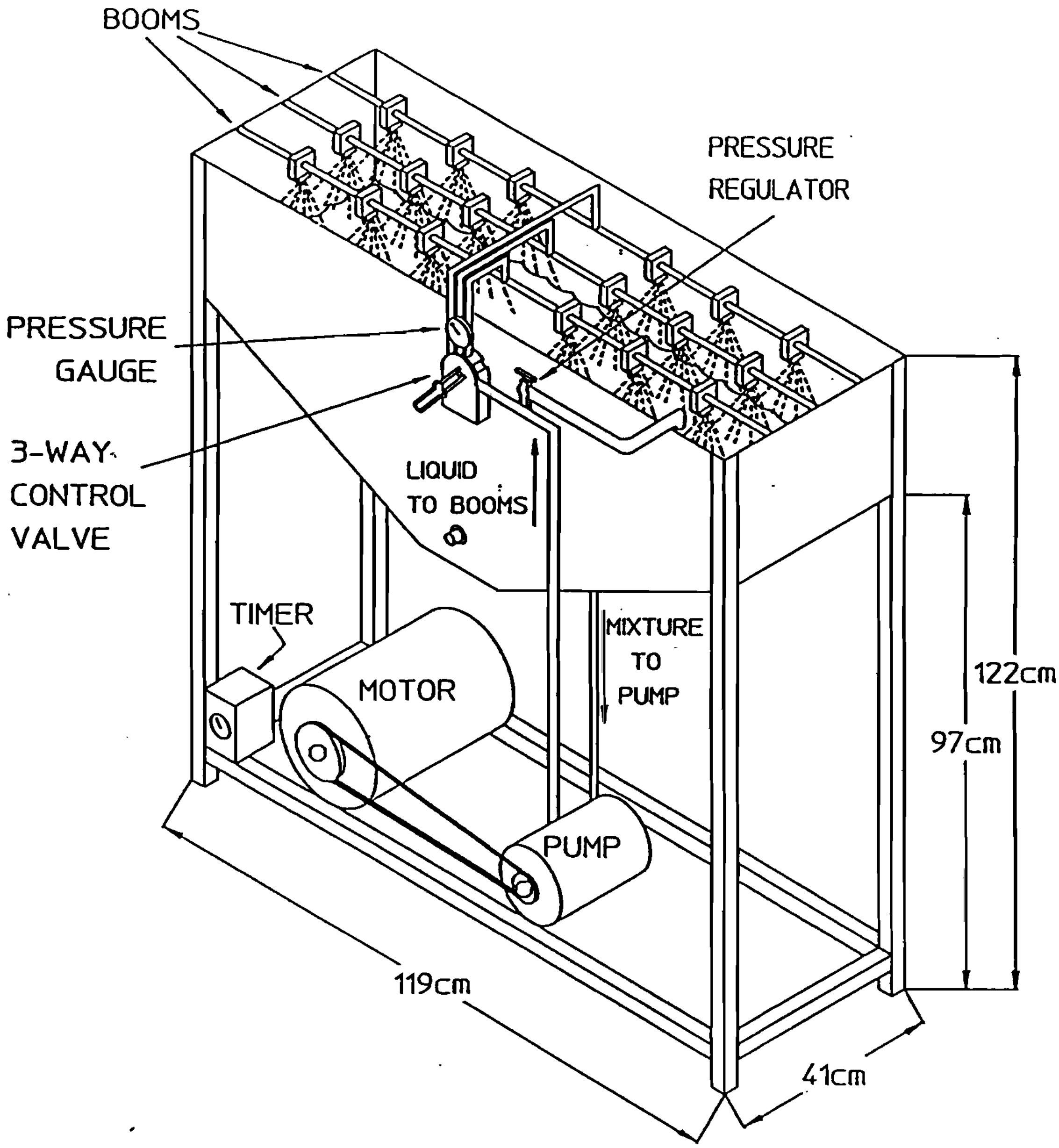


Figure 4. Nozzle wear test stand.

in 1989 for this purpose. It consists of a 208.2 liter (55 gallon) tank that holds the wearing agent solution. For these tests 60 grams of abrasive Flat D (Georgia Kaolin Co.) per liter (8 oz./gal) of water was used to wear the nozzles. This mixture was maintained in about 150 liters (40 gal) of water. The solution is mixed thoroughly by a mechanical agitator to keep the mixture in suspension. A diaphragm pump moves the suspension through a flow meter to a boom assembly which supports as many as 18 nozzles for wearing. More detailed information on this nozzle wear test stand and the procedure for wearing the nozzles is given by Reichard et al. (1991).

PROCEDURE

After conducting several calibration steps (see Figures 22 through 26 in Appendix A), various tests on this new pattern testing system were conducted to determine its accuracy and repeatability. These tests included a comparison of the new system versus the old system. Then, using this new system, several nozzle tests were conducted to examine the effects of wear on the spray pattern uniformity.

Survey for Comparison of Systems

To estimate the efficiency and accuracy associated with conventional spray patternators like those described previously, tests were conducted at the Ohio State University and the University of Delaware. Surveys were also sent to all 37 members of the ASAE PM-41 Pest Control and Fertilizer Application Committee, group of researchers most likely to have experience with patternators. The survey requested the following information:

a) A short description of the patternator used by the committee member,

b) Approximate cost of the patternator,

c) Time required for workers, both familiar and unfamiliar with the system, to collect pattern data for one nozzle,

d) Types of analyses done with the data collected, such as, graphical illustration of one nozzle, composite spray distribution, standard deviation, and Coefficient of Variation (described later),

e) Time required to complete the types of data analyses described above,

f) Types of experimental errors encountered with the patternator (or the types of human errors to which the patternator is susceptible).

Based on the results of this survey a comparison was made between the new automated patternator and a sampling of conventional patternators.

To study the time required to measure and record the data from conventional patternator cylinders, a typical spray pattern was generated from a fan-pattern nozzle on a system (referred to as patternator #1 from now on) similar to the one shown in Figure 1. Then ten students from the Ohio State University Agricultural Engineering Department, were asked to read the level of liquid in each of the 21 graduated cylinders while being timed. To demonstrate the influence of patternator design on the amount of time required to take data, a similar experiment was set up using a larger conventional patternator (patternator #2) with 30 graduated cylinders at the Agricultural Engineering Department, University of Delaware under the supervision of Dr. P. Krishnan. There were nine students participating in this second experiment.

Nozzle Testing Procedure

After determining the new system had acceptable accuracy and repeatability, testing could begin on the spray nozzles. The testing procedure began with the selection of the set of nozzles to be tested. The set consisted of 80° flat fan nozzles made of stainless steel, hardened stainless steel, nylon, brass, and plastic. These materials were tested in nozzles with capacities of 0.8, 1.5, 2.3, and 3.0 L/min (0.2, 0.4, 0.6, and 0.8 gpm). The nozzles were operated at 276 kPa (40 psi) and 48 cm (19 in.) boom height, which is within the range recommended by the nozzle manufacturers.

Tests were performed on representative nozzles, both new and worn, from each of the particular types listed above. The nozzles for this test were worn until a certain amount of increase in flow rate was measured (this exact amount will be discussed in the results section). This set of nozzles was used to compare spray distribution of nozzles made from different capacities and materials as they wore.

Another set of nozzles were worn to 5 stages of flow rate increase (10, 20, 30, 40, and 50%). This set included only brass 80° flat fan nozzles with 0.8 L/min (0.2 gpm) capacities. This set was used to compare the amount of wear to changes in distribution.

Data Collection Procedure

The procedure for spray pattern analysis consisted of several steps that were the same for all nozzle test sets. First the nozzle was adjusted to the desired height. Next the pump was turned on allowing the nozzle(s) to spray on the corrugated sections of the patternator. The spray pressure at the nozzle was adjusted to the desired level using the pressure regulator. The nozzle sprayed for a sufficient amount of time (10-20 sec.) to allow the spray to flow through and wet the entire patternator before any data was taken. This allowed the spray to fill the troughs and begin flowing off into the reservoir. Next the ASYST program was readied for data collection and the collection unit was put in motion by starting the electric motor that drives it. Both the position and the weight data were transferred to the computer for analysis while the collection unit was moving. The program accepted data over a distance of 210 cm (83 in) along the patternator; 105 cm (41.5 in.) on each side of the center of the nozzle. This provided a sampling distance that covered most of the patternator width while leaving room at each side to eliminate error induced by starting and stopping the collection unit.

The data sent to the software program was the position read by the sensor and the weight at that position as read by the balance. After the collection unit made a pass, the ASYST program was used to analyze this data. The analysis, including graphical presentation of the data, was completed immediately after the collection unit stopped. Approximately one minute was required from the time the collection unit started until the spray distribution data for one test trial of one nozzle was graphically displayed on the computer screen. To insure a greater accuracy, three trials were completed for each nozzle in the test set. A group of three representatives from each specific type of nozzle were tested. Because three test trials on each nozzle were conducted, nine groups of data for each specific nozzle type were obtained.

Data Analysis Procedure

The data analysis with ASYST software started immediately after the predetermined number of tests were completed. The program started by correcting both the weight and position data. This was necessary because the weight data was slightly distorted as a result of the balance not remaining level while travelling across the table; and the position transducer did not provide a perfectly linear representation of the position. However, the error found in each data set remained consistent for all test runs. Calibration curves, representing this error, were determined using another ASYST program to generate a polynomial equation. The coefficients for these polynomials were loaded in with the ASYST program that was used for data collection. One of the programs used to calculate these coefficients can be found in Appendix B. By subtracting the calibration curves from all the incoming weight and position data, this error was eliminated. Also, as the position data was recorded, it was rounded to the nearest centimeter. This was required for later data manipulation.

After the data was corrected it was combined into one large array. This array consisted of nine data sets corresponding to the nine test trials performed on each nozzle type in the test set. Then the computer program sorted and averaged the data so that only one average value for the weight was given at each centimeter of position. Next the data was sent through a smoothing routine to eliminate vibrational noise from the system. This smoothing could have been accomplished within a wide range of sensitivity controlled by the user. The sensitivity was set so that any vibration occurring between patternator troughs (3.5 cm or 1.4 in.) would be smoothed. Ideally this should have helped to eliminate the sudden change in weight that occurred when the collection unit passed one trough and began accepting liquid from a new one. The effects of changing the smoothing cutoff frequency are illustrated in Figure 26 (Appendix A).

After the data was sorted, averaged, and smoothed it was then plotted in its cumulative weight form (Figure 5). This graph was basically a representation of the raw data, or what would be seen if one watched the display on the balance as it traveled (except that this data was now the average for all nine test trials). It was from this data that the change in weight curve was developed (Figure 6). This was accomplished by taking a simple two point derivative of the cumulative data.

The final portion of the program allowed the user to input a nozzle spacing for use in simulating a composite spray distribution across a section of a boom, as illustrated in Figure 7. Using only one (actually nine trials combined into one) nozzle's data, this simulation was accomplished by making each nozzle on the boom have this exact same spray pattern. Based on the input nozzle spacing, the boom distribution was then simulated simply by adding the weight of water contributed by each of the identical nozzle spray patterns at each position. Research has proven that this provides an adequate simulation of the distribution of a spray boom (Underwood, 1990). The uniformity of the nozzle can then be

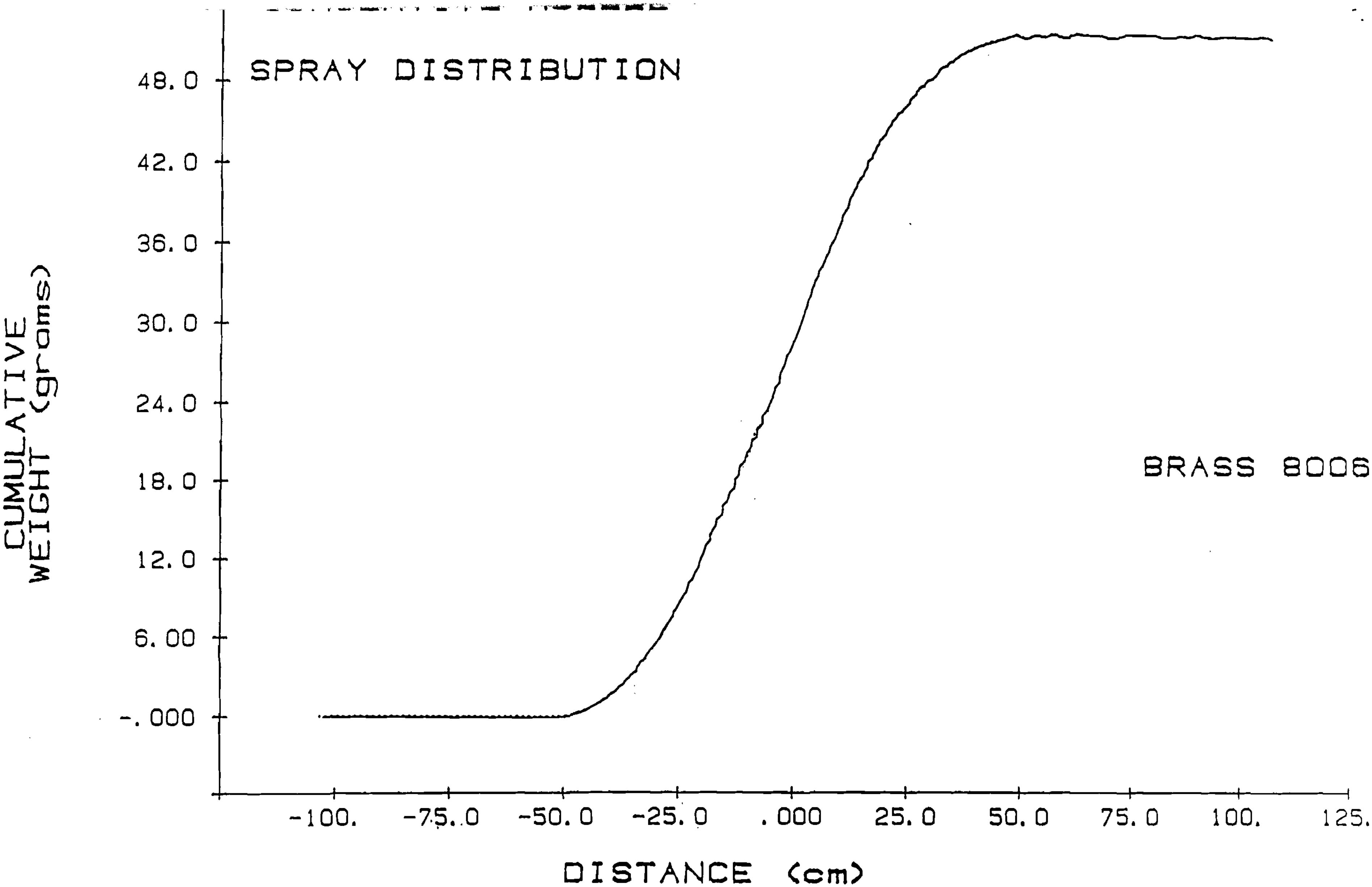


Figure 5. Example of cumulative weight graph plotted by ASYST.

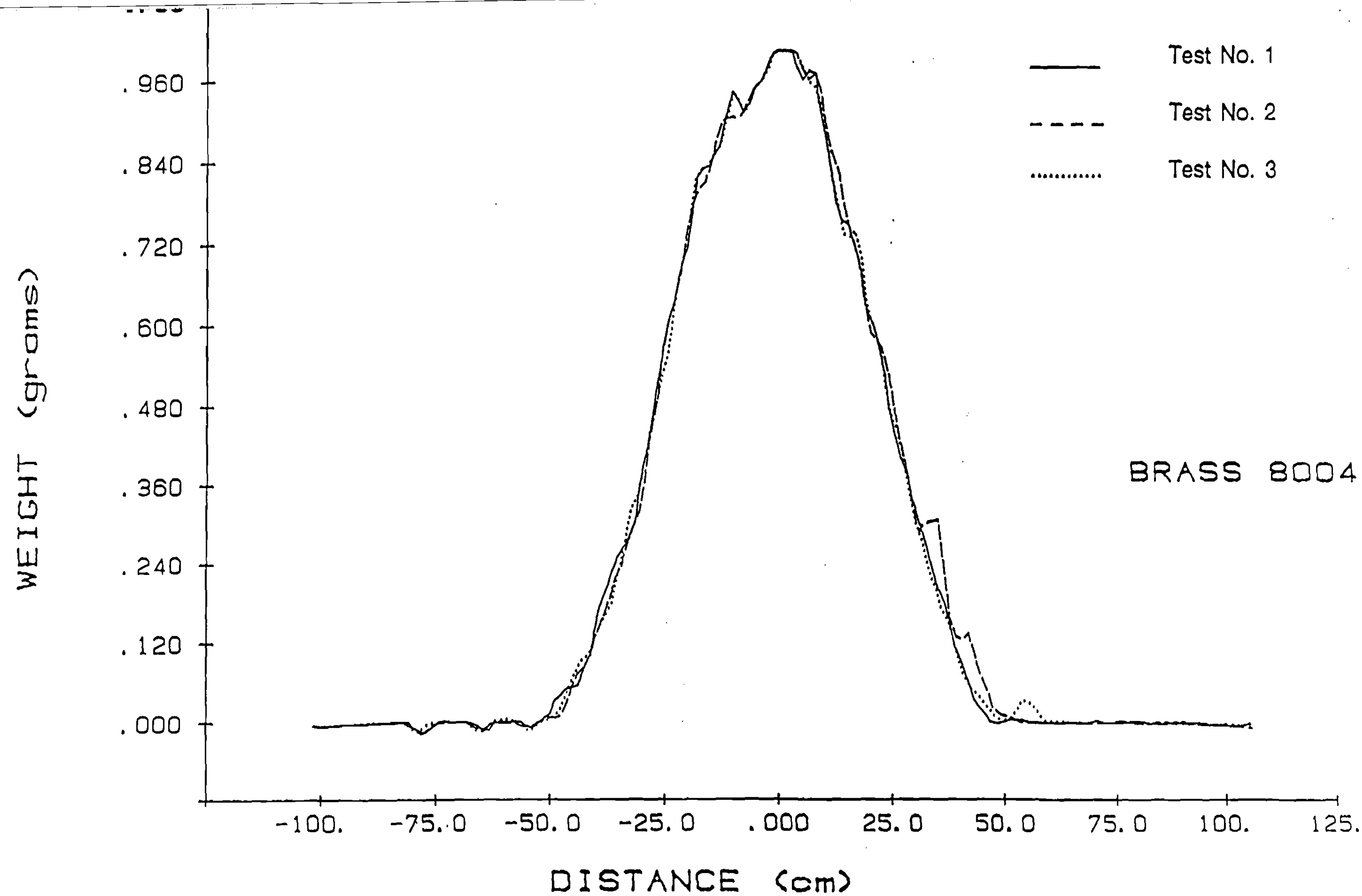


Figure 6. Example of change in weight curve.

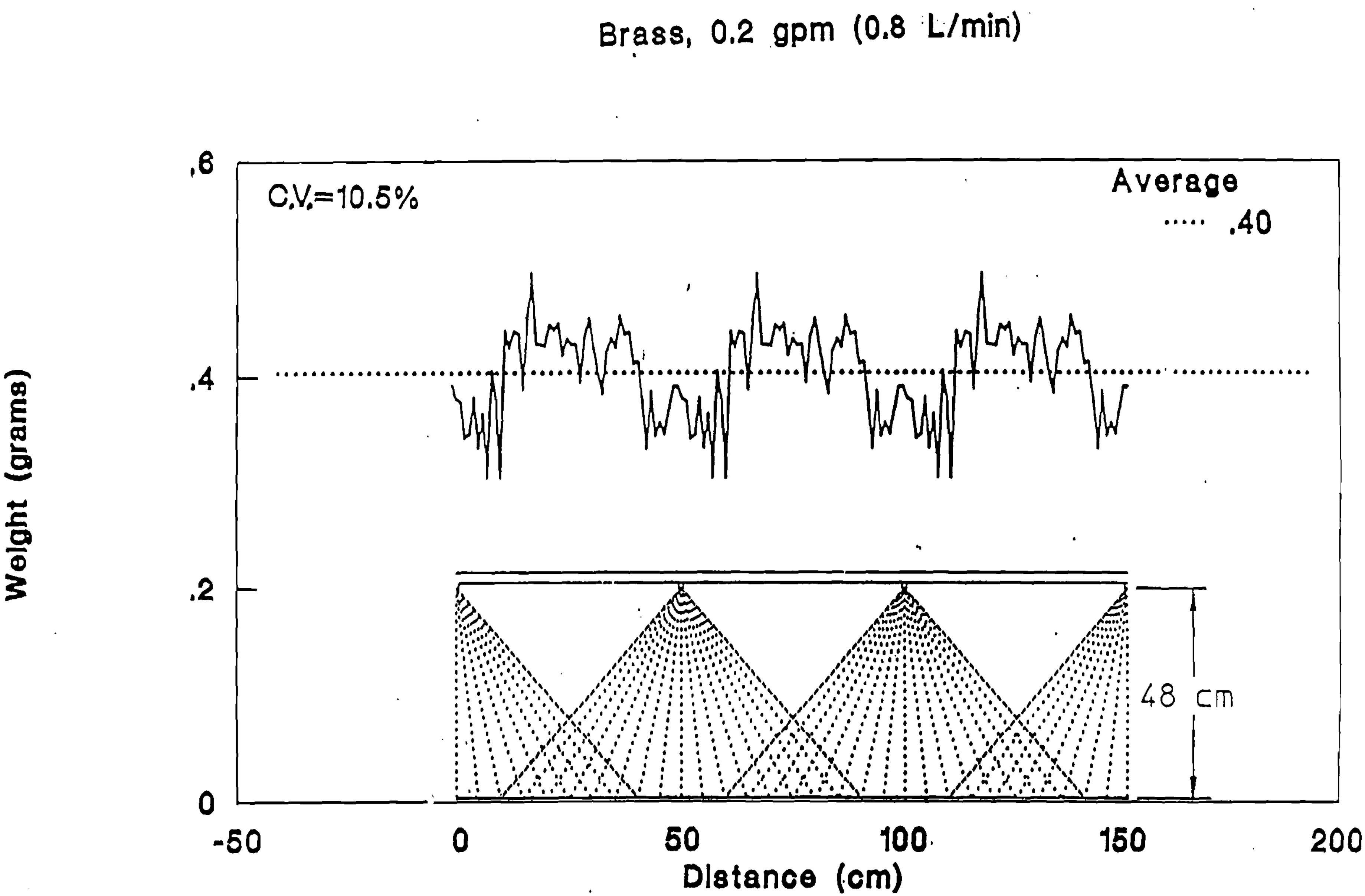


Figure 7. Example of uniformity analysis: a simulated composite spray distribution across a section of a spray boom.

determined visually.

Next the Coefficient of Variation (CV) was computed so that a numerical representation of uniformity could also be used for comparison. The CV of a spray distribution is widely used by many researchers to evaluate application uniformity. It is, as expressed in Equation 1, the standard deviation of the spray distribution divided by the mean of the distribution.

$$\%C.V. = \frac{\sqrt{\frac{\Sigma(X_i-\bar{X})^2}{n-1}}}{\bar{X}} x\,100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where

X_i = Amount of spray deposited at the i^{th} sample of the spray swath

X = Mean spray distribution across the spray swath

n = Number of measurements

The higher the CV the greater the variation in the distribution. Values of CV below 10% indicate acceptable variation in coverage while CV values greater than 15% indicate unacceptable variation (Azimi et al., 1985; PAMI, 1989).

The final portion of the program was set up to allow the user to repeat this last step of the analysis. By entering new values for the nozzle spacing during successive program runs the user could rapidly determine the nozzle spacing that produces the lowest CV, or the most uniform spray distribution across the spray swath for that particular boom height.

Once the analysis of the previously mentioned nozzle data sets were completed, the results were compared. The nozzle set for comparison of new versus worn nozzles of different materials and different capacities were plotted in new versus worn graphs for each type and capacity (Figures 12 through 20). The nozzle set of various stages of wear had all six curves plotted on one graph for easy comparison (Figure 21).

RESULTS

This section presents the results of several tests using the new system and conclusions based on these results. This section also presents the results obtained by analyzing the new system. This is to show that the new system meets the previously stated criteria.

Survey Results

Twelve of the 13 survey forms returned had responses to all of the questions. Two of the respondents (both with nozzle manufacturing companies) constructed automated patternator systems. One company implemented an imaging system which sent a photograph of the liquid height in the cylinders to a computer. The other had two types of patternators. One had a weight transducer at the bottom of each cylinder, and once a predetermined maximum reading in any one cylinder was reached, spraying stopped and the weight data from all of the cylinders was sent directly to a computer. The second system used a single top loading balance mounted on a carriage which moved along under the cylinders and stopped to measure the weight of liquid collected in each cylinder. Each of these systems used a computer to directly receive the data from the measuring devices. This eliminated potential error and saved time because the data was no longer manually collected and entered into a computer. Although these automated systems performed satisfactorily for the most part, their cost ranged from $8,500 to $100,000 and one of these systems still took as long as 25 minutes to gather and analyze data from one test (reading 100 cylinders).

The other ten respondents had conventional, non-automated patternators with graduated cylinders. The cost of these patternators varied from $100 to $1,200 with an average of about $800. The time required to collect data for one nozzle using these patternators averaged 10 minutes, with responses ranging from 2 to 25 minutes (based on nine responses). Patternators with narrower channels and more cylinders required more time to collect data than smaller patternators with fewer cylinders. For this reason the time data was converted to a time per cylinder. On a per cylinder basis, the average time to collect data was 15 seconds (based on seven responses which included information on the number of cylinders and the total time required to read data from all cylinders). Analyzing data from one nozzle required 10 to 30 minutes with an average time of 22 minutes (based on seven responses).

The survey results also indicated that the conventional patternators, equipped with cylinders, are highly susceptible to human error while recording data. The two major sources of error mentioned by the respondents were: 1) not reading the data correctly (even changes in the position of the person taking the data could cause an error), and 2) data taken by different people. Errors could also be made while recording the data on paper or while transferring data from paper to a computer or a calculator.

The results of the time trials for each of the patternators mentioned earlier are summarized in Figures 8 and 9. Once again the percent Coefficient of Variation (CV) was used as a measure of variability. In this case the variability was measured in the data recorded by different people for the same cylinder or tube. Equation 1 is expressed here in a slightly different form. In this case CV represented the standard deviation of the data taken by different people for the same tube divided by the mean value of the data recorded.

$$\%C.V._j = \frac{\sqrt{\frac{\Sigma(X_i - \bar{X})^2}{n-1}}}{\bar{X}} x\,100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where

X_i = Amount of liquid recorded by the i^{th} student from the j^{th} tube

i = 1 through 10 for patternator #1, and 1 through 9 for patternator #2

j = 7 through 27 for patternator #1, and 1 through 30 for patternator #2

X = Mean of data taken by students from the j^{th} tube

n = Number of students taking data from the j^{th} tube

Higher values for CV in this case indicated greater variation in the data recorded by different people for the same tube.

Figure 8 shows the percent CV associated with the data taken from each of the graduated tubes of patternators #1 and #2. The data was taken from tubes 7 through 27 with patternator #1, and tubes 2 through 30 with patternator #2. Since the magnitude of the variation in readings was related to the precision of the markings on the cylinders, and all the cylinders were the same, the variation in liquid volume readings should have been the same in all of the cylinders. However, as indicated in Figure 8, the percent CV's of readings for both patternators were much smaller when recording data from the cylinders near the center of the patternator than those close to both ends. This was probably because the volume of spray from flat-fan nozzles, such as the ones used in these tests, tapered off toward both sides of the spray pattern. The result was very low liquid levels in cylinders towards both ends, which corresponded to a lower value for the mean volume of these tubes. When computing CV, this lower mean volume for the same standard deviation gave larger CV's.

No data was available as to how much variation was acceptable when readings were taken from graduated tubes. However, it was assumed that a similar analysis could be applied here as when using the CV as a measure of spray distribution uniformity across a spray swath. This analysis, as described earlier, was that CV's above 10 to 15% indicated unacceptable variation (Azimi et al., 1985; PAMI, 1989). Using these criteria, the variation was generally acceptable at the centers of the patternators, but it reached unacceptable levels towards both ends. There were only 9 out of the 47 tubes of both patternators that had CV's greater than 10%. The CV's associated with the first two tubes (tube numbers 7 and

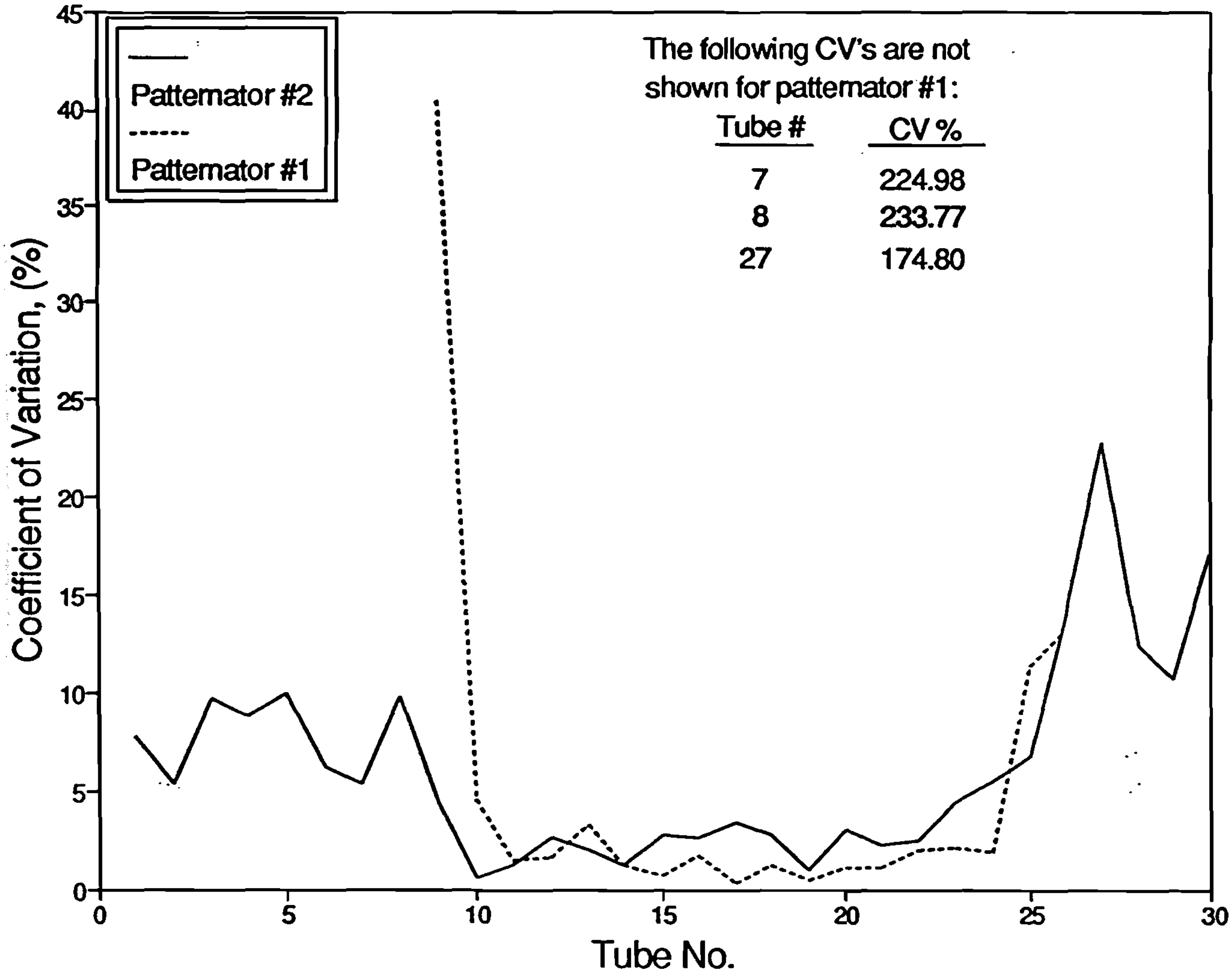


Figure 8. Percent Coefficient of Variation associated with the data taken from each graduated tube of patternators #1 and #2.34

8), and the last tube (tube number 27) of patternator #1 were 225, 234, and 175 percent respectively.

The time required to measure and record the data from conventional patternator cylinders varied considerably depending on who was taking the data (Figure 9). While it took only 3.6 minutes (12 seconds/cylinder) for one student to read and record the data from patternator #1, another student needed 9.3 minutes (31 sec/cylinder). The average time for ten students was 5.8 minutes (19.3 seconds/cylinder). For a similar test with patternator #2, the average time for nine students to record the data from the 30 cylinders was 4.2 minutes (8.5 seconds/cylinder).

To compare the survey and patternator test results to the performance of the new automated system the data was combined into a summarized form. The average time for data collection for all conventional patternators was 7 minutes, which included the results of nine survey responses as well as the tests on patternators #1 and #2. On a per cylinder basis, the average time for data collection for all conventional patternators (includes patternator tests and seven survey responses) was 13 seconds. Finally, from seven survey responses alone it took an average of 34 minutes to complete a test which included both collecting and analyzing the data.

The new automated patternator, on an equivalent per cylinder basis, took about 1 second for data collection from one test of one nozzle (obtained by considering each trough on this patternator as equal to one cylinder). This would allow about thirteen nozzles to

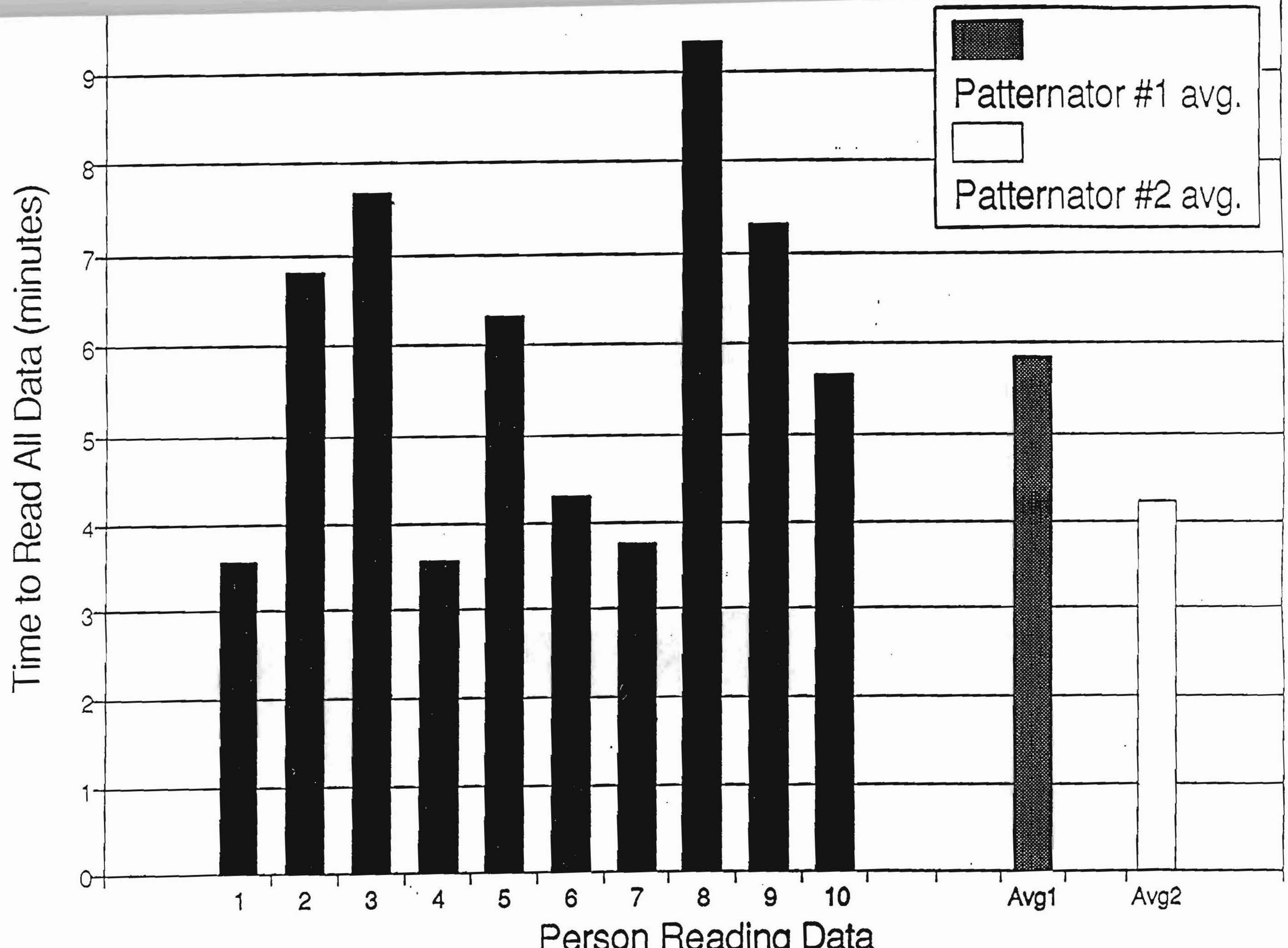


Figure 9. Time required to read all the data from the 21 graduated cylinders of patternator #1, the average time for all 10 students to read all the data of patternator #1, and the average time for 9 students to read all the data of

be tested during the same amount of time it took to test one nozzle on the average conventional system (1 versus 13 seconds per trough). However, as mentioned earlier, the procedure was to test each nozzle three times. Even so, the data collection time was only about 3 seconds per trough or about 4 times faster than the average conventional patternator.

Criteria Analysis

The previously listed criteria were used to determine the feasibility of the new automated system once the design was complete. Several analyses were performed on the system, such as: an analysis of the method of data collection, a cost determination, a repeatability analysis, and an accuracy analysis. The new system was also designed to retain some positive characteristics of the conventional patternator, including: the capability to test all types of nozzles in normally mounted positions and it did not interfere with the spray pattern before the data was collected.

1. Method of Data Collection

The speed required for data collection was determined by observing several test runs using the new system. The final decision was to use a speed that would allow the collection unit to gather approximately one data point for each centimeter of position travelled. It was also determined that at slower speeds the collection unit no longer moved at a constant rate due to friction encountered in the drive system. From these conditions it was decided that a speed of approximately 3.5 cm/s (i.e. about 1 second per trough or 1.4 in./s) was reasonable. As mentioned before, this speed allows data collection at a much faster rate than that of the average conventional system.

This speed was achieved by allowing the computer to gather data continuously as the collection unit moved along the table. There was no longer a need to let the system run as long as on conventional patternators where the graduated cylinders had to be filled to a certain level for accurate readings. Also, the time and labor required for the researcher to read, record, and enter the data into a computer was eliminated by sending the data directly to the computer. This direct computer data reception also helped to eliminate the error that occurred during human gathering and handling of the data.

2. Relative Cost

To build this entire system required a cost of approximately $4,500. This estimate was based on a cost of $1,000 for the spray table and spraying system. The other $3,500 included the costs of the drive system, the top-loading balance, the position sensor, the data acquisition computer system, and the ASYST software package.

The new system cost was about $3,700 more than conventional systems but this cost was justified by the increase in efficiency and decrease in labor. Compared to other automated nozzle testing systems which cost greater than $8,500, this new system had a relatively low cost.

3. Repeatability

The results from repeatability analysis indicated that tests performed under the same operating conditions yielded similar results. These results can be seen more clearly from Figure 10 which shows the data from three tests on the same nozzle operating under the same conditions. The results were nearly identical for all three tests.

4. Accuracy

The new system was found to be relatively accurate compared to conventional systems. Figure 11 shows the data obtained by performing tests on the new system and on a conventional system for the same nozzle using the same operating conditions. Since the data was approximately the same, it was assumed that the new system was relatively accurate.

Nozzle Test Results

The following is a summary of results related to the effect of orifice wear on nozzle flow rate. The detailed results were given by Reichard et al. (1991). Tests to measure the increase in flow rate with wear were stopped when there was about a 10% increase in flow rate through stainless steel nozzles. Brass nozzles were not tested as many hours as other nozzles (nylon, plastic, stainless steel, and hardened stainless steel) because the brass nozzles wore more rapidly. Table 1 shows the number of hours the nozzles were subjected to wear tests and the percent flow rate increase at the end of the test period. The values for the percent flow rate increase were the average values of three representatives tested from each specific type of nozzle that had the same material and capacity.

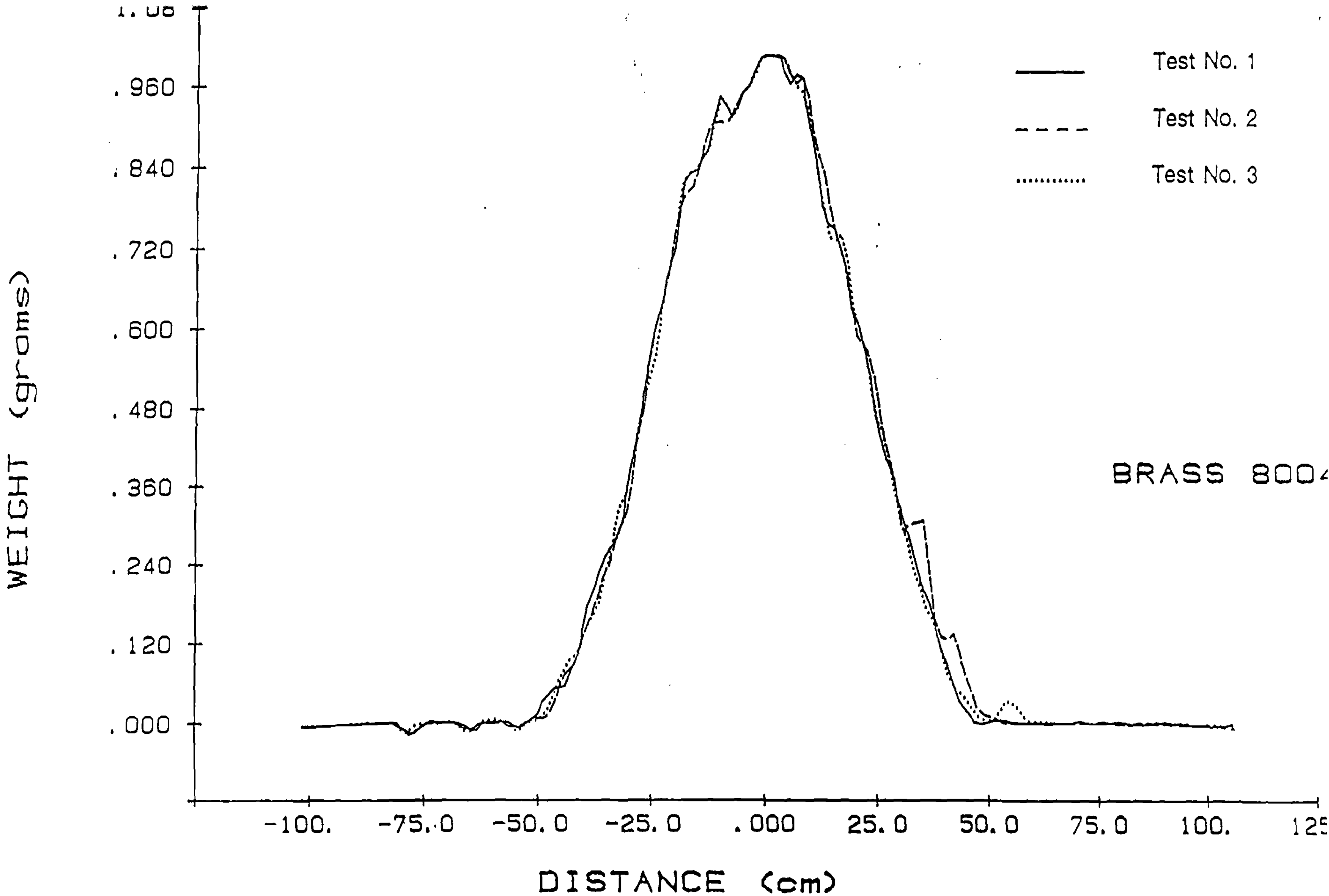


Figure 10. Example of change in weight curve and illustration of repeatability.

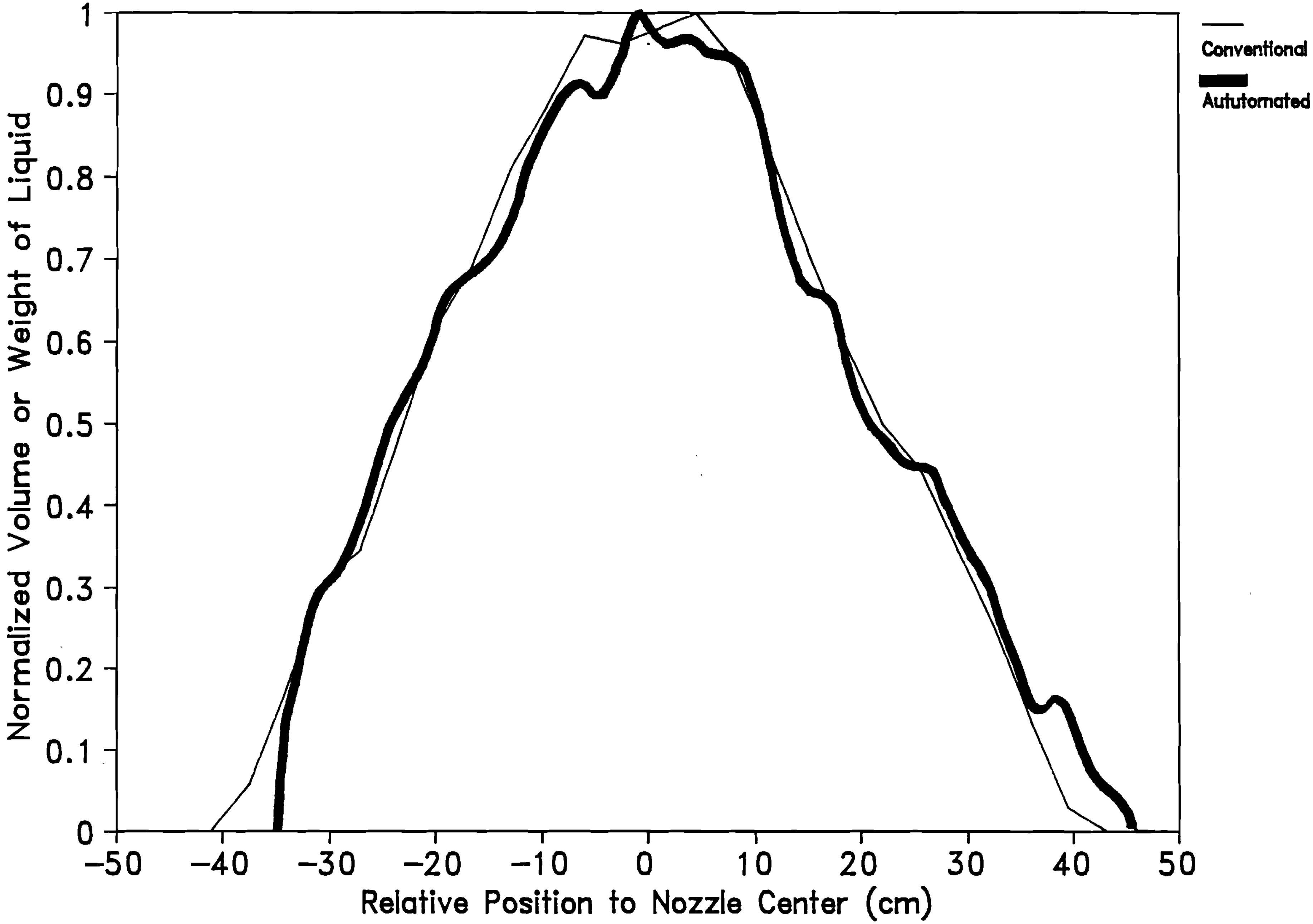


Figure 11. Comparison of accuracy between a conventional patternator and the automated patternator.

Table 1. Duration of wear tests and increase in flow rate of nozzles at the end of the test period.

Nozzle Capacity L/min	(gpm)	Brass Test Period (Hr)	Brass Increase in flow rate (%)	Nylon Test Period (Hr)	Nylon Increase in flow rate (%)
0.8	(0.2)	26	22.8	40	15.8
1.5	(0.4)	44	19.6	100	17.9
2.3	(0.6)	110	21.0	242	23.8
3.0	(0.8)	268	20.2	352	17.7

Nozzle Capacity L/min	(gpm)	Plastic Test Period (Hr)	Plastic Increase in flow rate (%)	Stainless Steel Test Period (Hr)	Stainless Steel Increase in flow rate (%)
0.8	(0.2)	40	18.1	40	14.0
1.5	(0.4)	100	12.4	100	12.2
2.3	(0.6)	242	14.0	242	12.6
3.0	(0.8)	352	13.5	352	11.0

Nozzle Capacity L/min	(gpm)	Hardened Stainless Steel Test Period (Hr)	Hardened Stainless Steel Increase in flow rate (%)
0.8	(0.2)	40	1.5
1.5	(0.4)	100	5.5
2.3	(0.6)	242	5.3
3.0	(0.8)	352	10.2

When tests to determine the changes in flow rates were completed, the same worn nozzles were used to determine changes in spray distribution patterns due to orifice wear. Initial tests showed variations in spray patterns of identical nozzles, both new and worn, under the same test conditions. Although the repeatability of the distribution measurements was illustrated earlier in Figure 10, the spray distribution measurements were repeated three times for each nozzle tested.

Figures 12, 13, 14, and 15 show spray patterns of nozzles with initial capacities of 0.8, 1.5, 2.3, and 3.0 L/min (0.2, 0.4, 0.6, and 0.8 gpm) respectively, both when nozzles were new and after they were worn. The percent increase in flow rates for the worn nozzles is shown in Table 1. Each data point on the graphs in Figures 12 through 15 represents a composite value of nine measurements. As mentioned earlier, these nine measurements were obtained by running three tests on each of the three representative nozzles of a specific type.

The results generally indicated there was little difference between the widths of spray deposit patterns of new and worn nozzles. However, there was greater difference between new and worn nozzles in volumes of liquid collected in the centers of the patterns than at the edges of the patterns. One can conclude from this information that adequate coverage and uniform distribution can be obtained from worn nozzles by making appropriate changes in boom height and/or nozzle spacing.

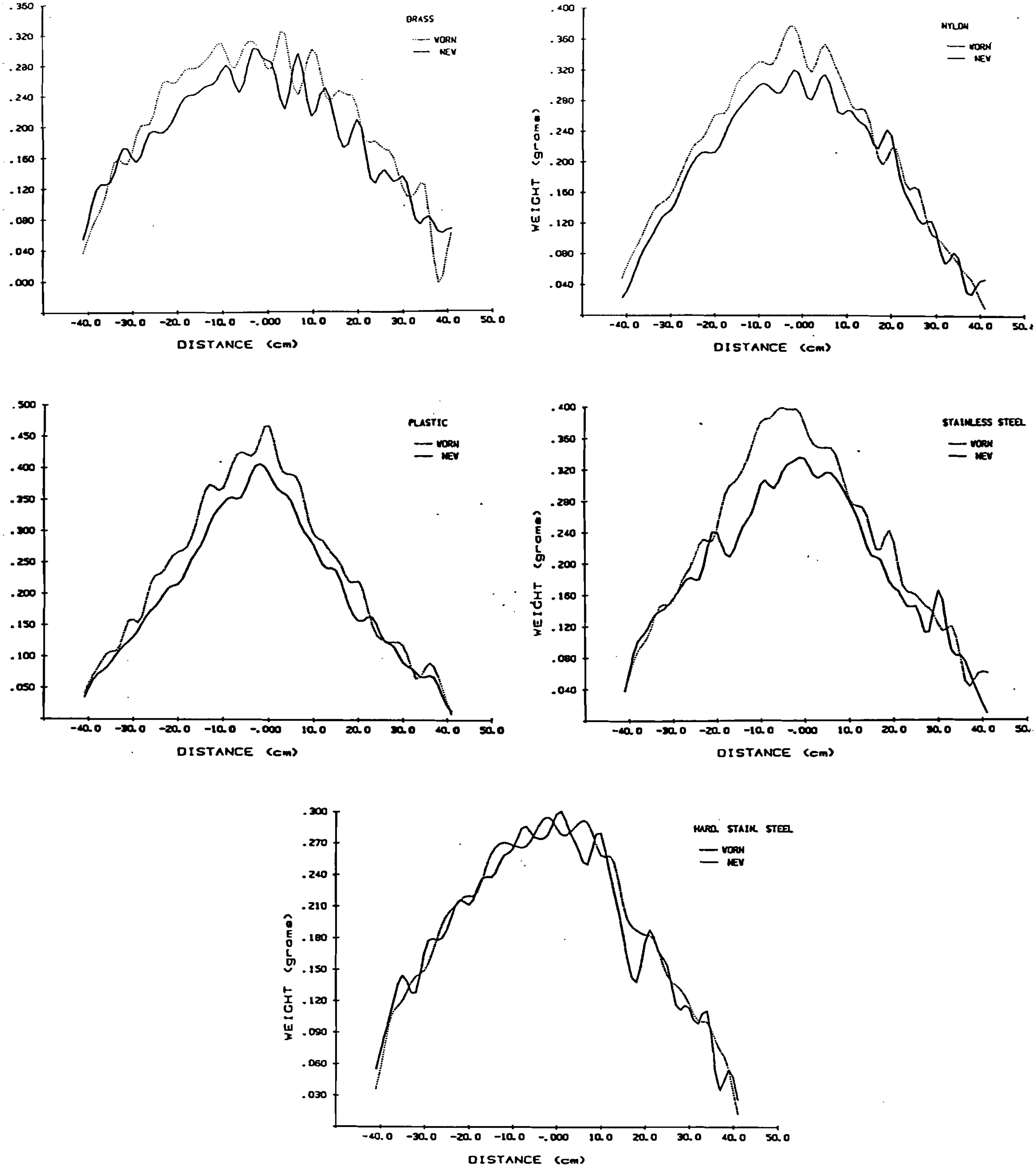


Figure 12. Spray distributions of new and worn nozzles constructed with different materials [Nominal Flow Rate: 0.8 L/min (0.2 gpm)].

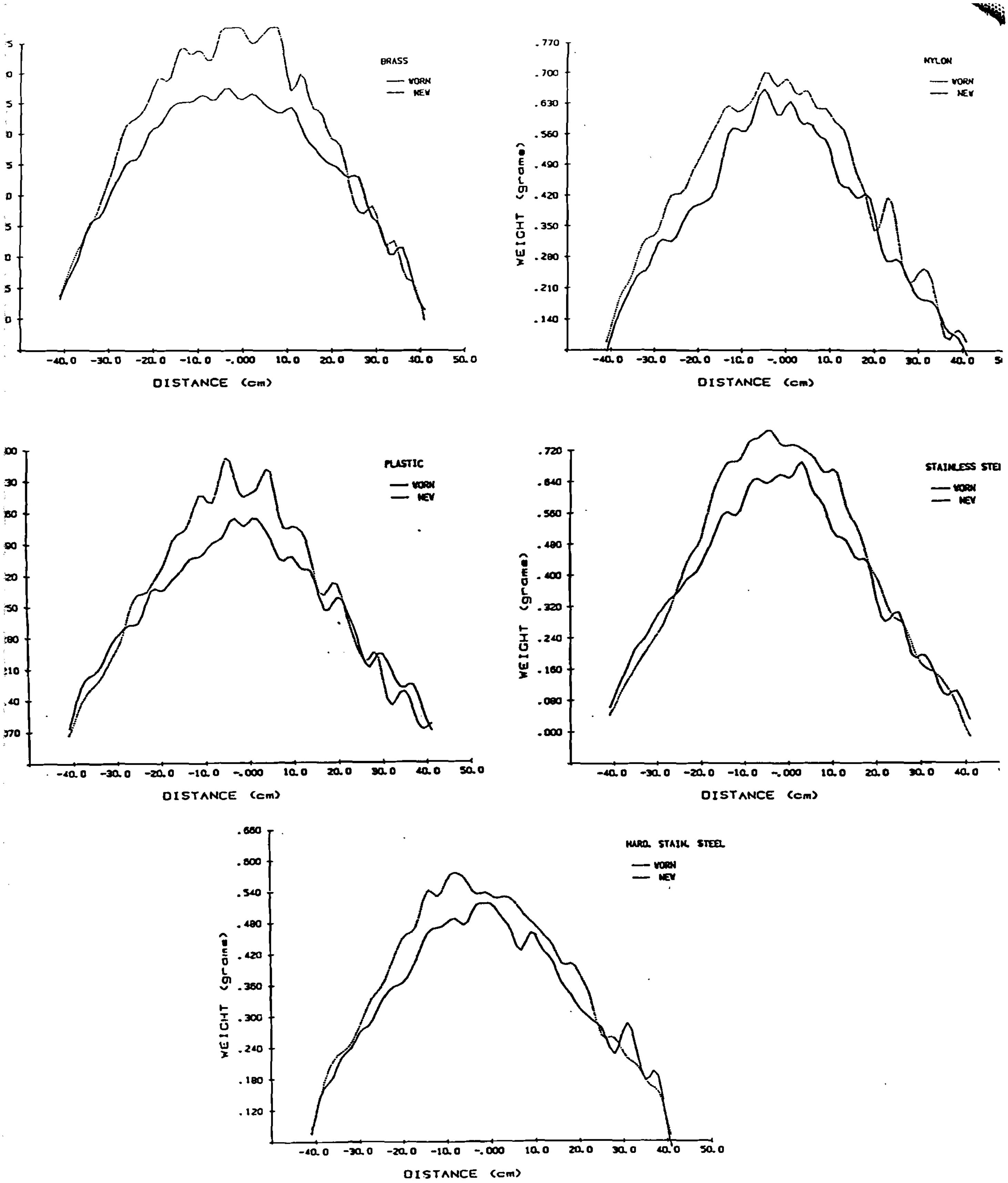


Figure 13. Spray distributions of new and worn nozzles constructed with different materials [Nominal Flow Rate: 1.5 L/min (0.4 gpm)].

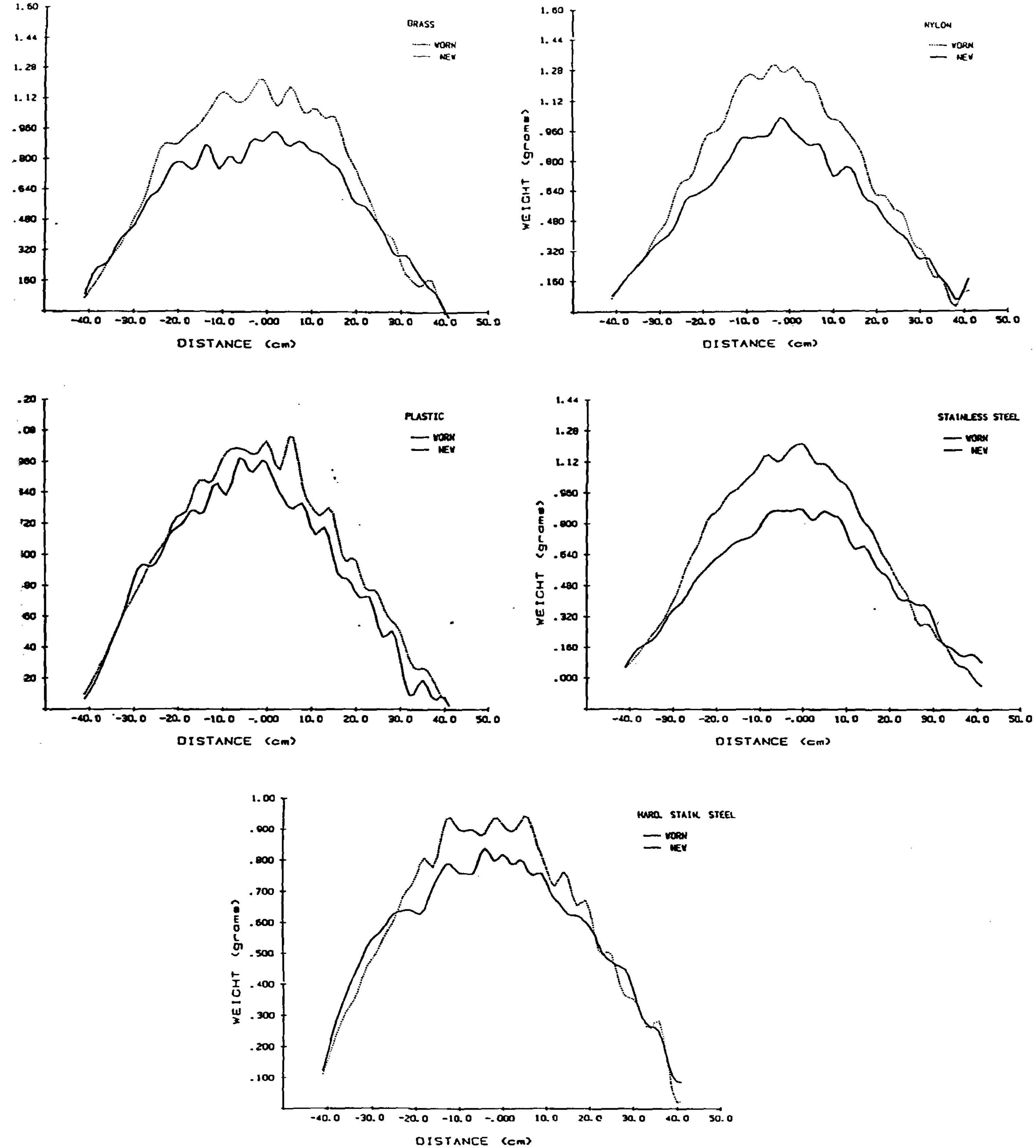


Figure 14. Spray distributions of new and worn nozzles constructed with different materials [Nominal Flow Rate: 2.3 L/min (0.6 gpm)].

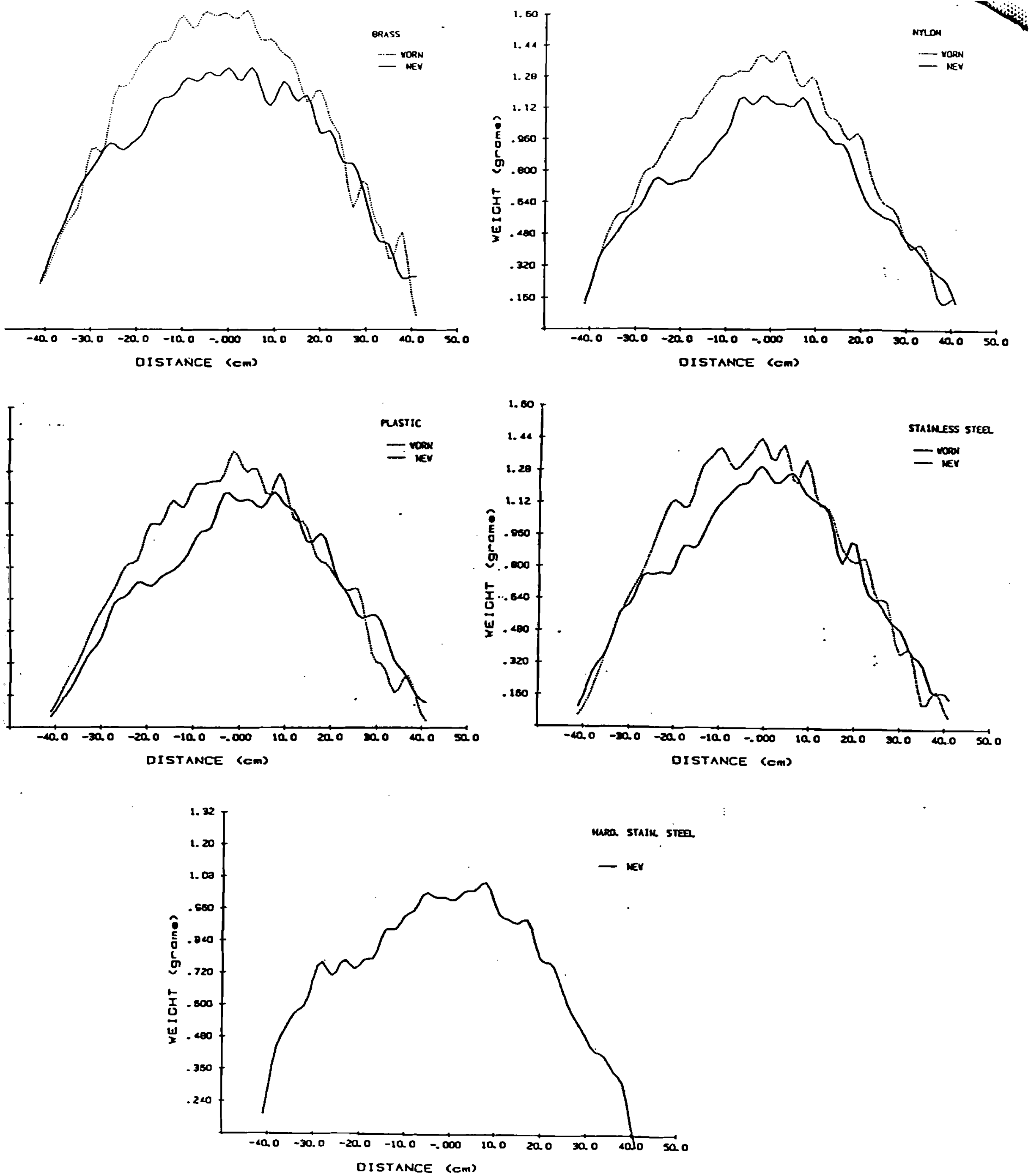


Figure 15. Spray distributions of new and worn nozzles constructed with different materials [Nominal Flow Rate: 3.0 L/min (0.8 gpm)].

Using the actual distribution data for one nozzle obtained from the patternator, a composite spray distribution for a short section of a spray boom was simulated. The initial values for nozzle height and spacing for this simulation were set at 48 and 51 cm (19 and 20 in.) respectively. These values were within the range recommended by nozzle manufacturers for 80° flat fan nozzles in order to achieve a spray distribution with the least amount of variation across the spray swath. Simulated spray distributions of new and worn nozzles with flow rates of 0.8, 1.5, 2.3, and 3.0 L/min (0.2, 0.4, 0.6, and 0.8 gpm) are illustrated in Figures 16, 17, 18, and 19 respectively. For these simulations, four nozzles were assumed to be positioned 51 cm (20 in.) apart at 0, 51, 102, and 153 cm (0, 20, 40, and 60 in.) along the boom. Simulation of a boom with an ideal spray distribution would result in data that forms a straight line parallel to the horizontal axis. Observation of the data presented in Figures 16 through 19 indicate that with the recommended settings for nozzle height and spacing there was some variation in the spray distribution along the boom. Also evident from these figures was that the distribution uniformity from some worn nozzles was better than new nozzles of the same type.

The Coefficient of Variation was used to evaluate application uniformity (Equation 1). The criteria for these values was that CV's below 10% indicated acceptable variation in coverage while CV's above 15% indicated unacceptable variation (Azimi et al., 1985; PAMI, 1989). Results from CV analysis of new and worn

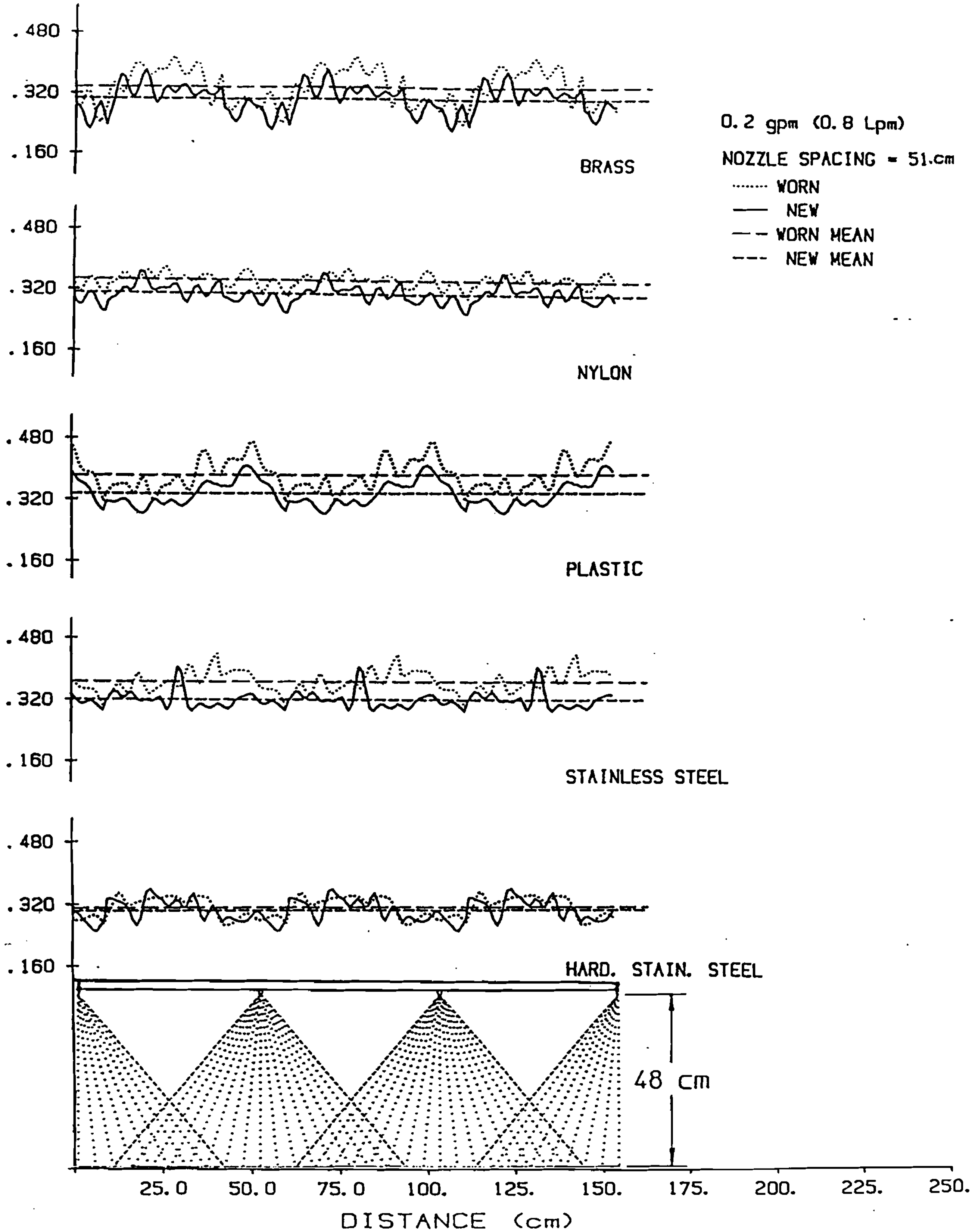


Figure 16. Simulated spray distributions of new and worn nozzles constructed with different materials [Nominal Flow Rate: 0.8 L/min (0.2 gpm)].

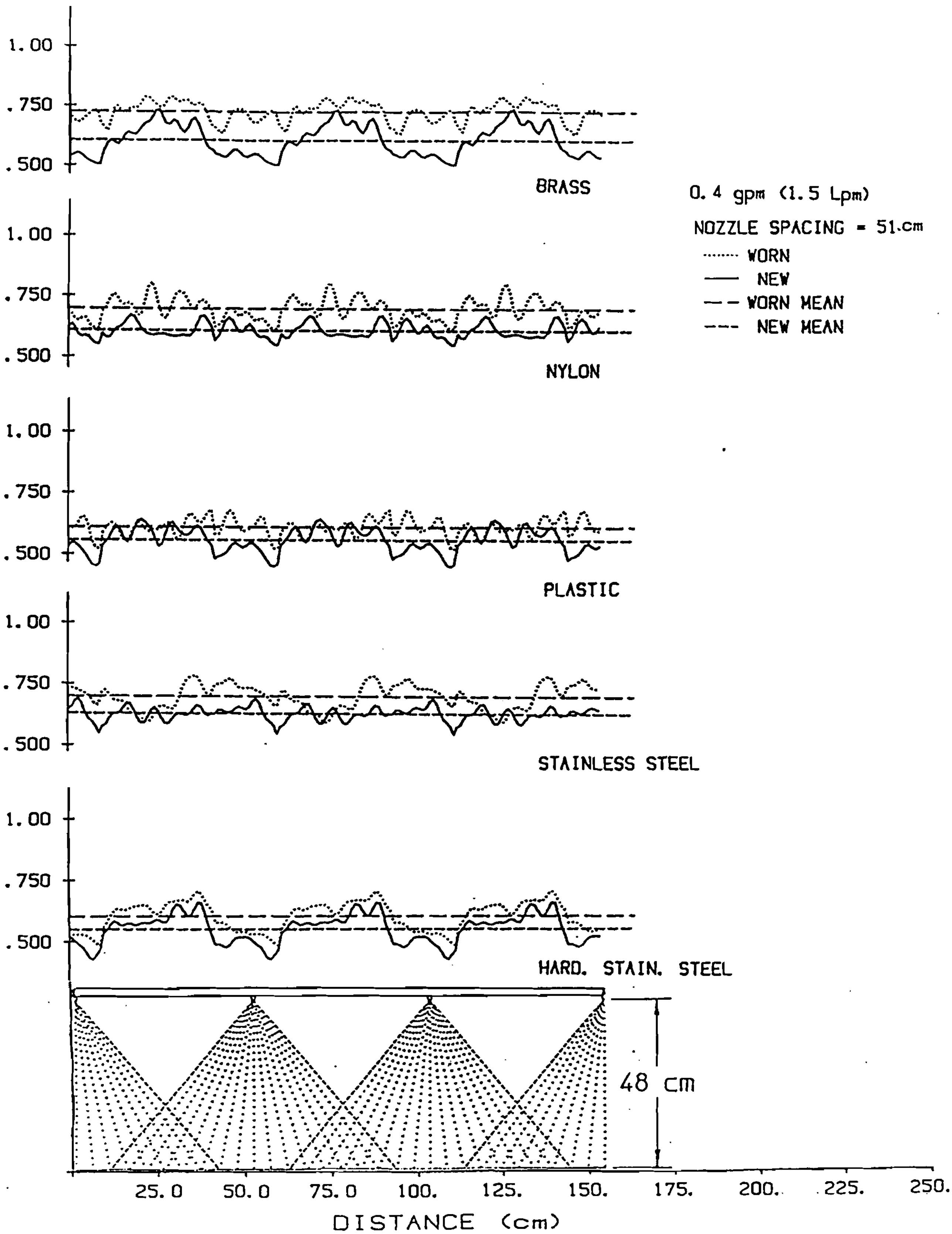


Figure 17. Simulated spray distributions of new and worn nozzles constructed with different materials [Nominal Flow Rate: 1.5 L/min (0.4 gpm)].

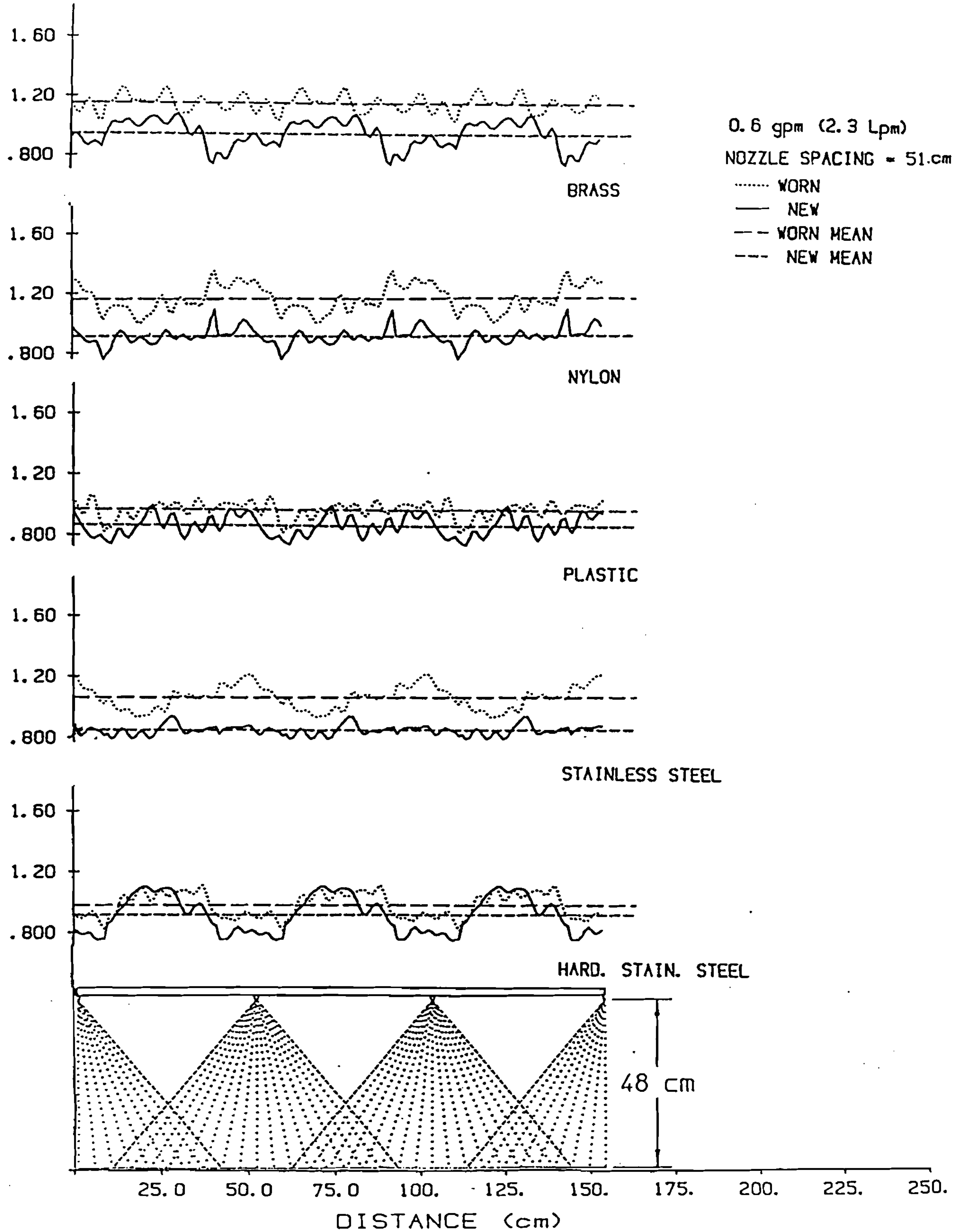


Figure 18. Simulated spray distributions of new and worn nozzles constructed with different materials [Nominal Flow Rate: 2.3 L/min (0.6 gpm)].

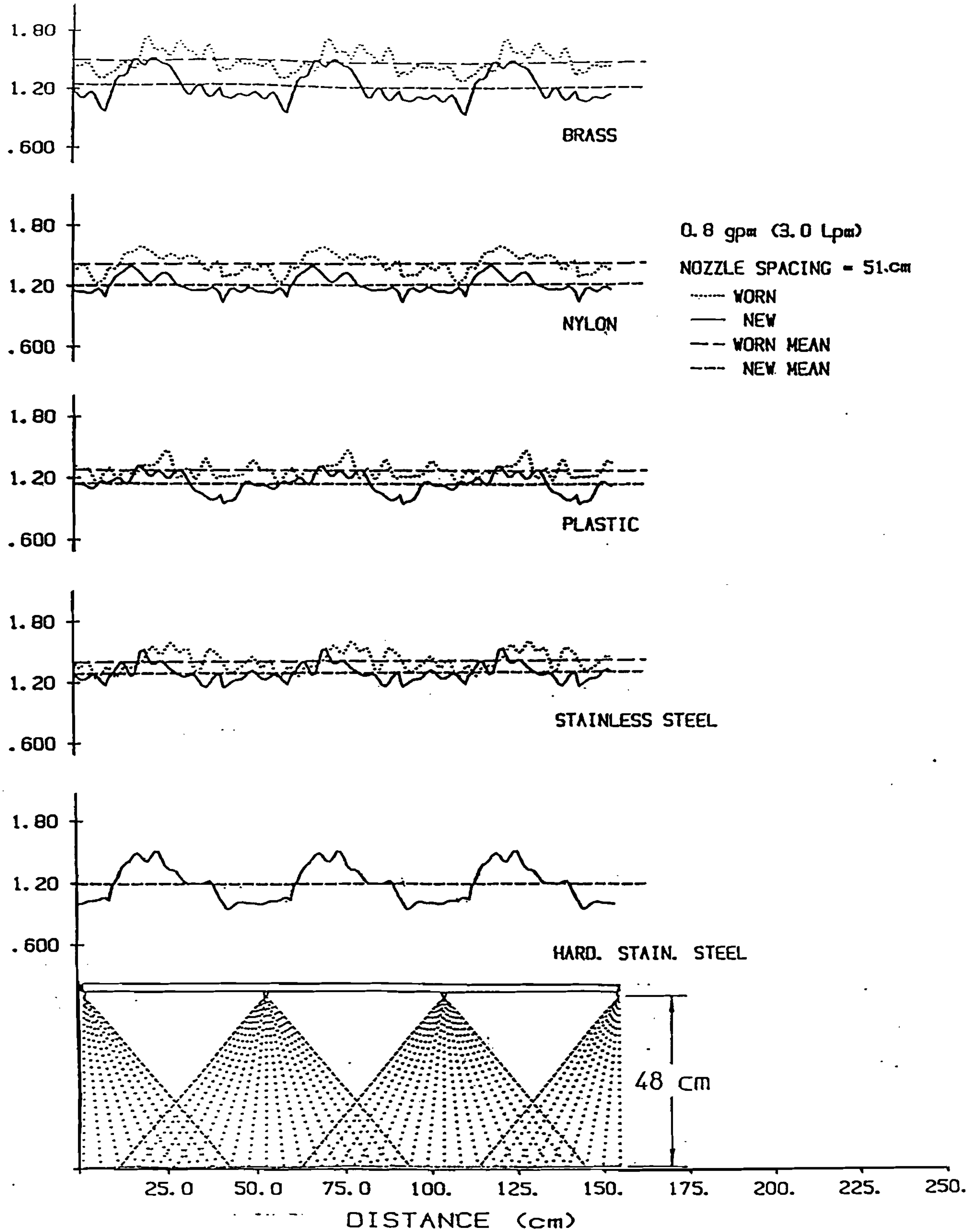


Figure 19. Simulated spray distributions of new and worn nozzles constructed with different materials [Nominal Flow Rate: 3.0 L/min (0.8 gpm)].

nozzles made from different materials are summarized in Table 2 and Figure 20.

All worn and new nozzles tested provided distributions with CV's lower than 15%. The CV's of spray distributions from worn brass, plastic and hardened stainless steel nozzles were generally lower than those from new nozzles constructed of the same materials. For all four nozzles capacities, CV's from new stainless steel nozzles were lower than those of worn stainless steel nozzles. In 11 of 19 (58%) comparisons of new and worn nozzles, the worn nozzles delivered distributions with smaller CV's than new nozzles. The largest decrease (5.12%) in CV of the spray distribution due to wear occurred with 1.5 L/min (0.4 gpm) brass nozzles. Among the new nozzles tested, distributions from hardened stainless steel nozzles had the highest mean CV (12.08%), followed by brass (11.14%), plastic (8.80%), nylon (6.41%), and stainless steel (5.51%) (Table 2). Among the worn nozzles, hardened stainless nozzles delivered distributions with the highest mean CV of distribution (8.89%), followed by brass (8.06%), stainless steel (7.28%), plastic (6.87%), and nylon (6.46%). For new nozzles 65% of the spray distributions had CV's less than 10% and 90% had CV's less than 13%. For worn nozzles 90% had CV's less than 10%. Among worn nozzles, 0.8 L/min (0.2 gpm) brass nozzles delivered distributions with the highest CV but they were also worn more than any of the other nozzles. Worn nylon nozzles with 0.8 L/min (0.2 gpm) nominal flow rate delivered distributions with the lowest CV (4.98%). Nozzles from all but one capacity of the new hardened

Table 2. Percent Coefficient of Variation of spray distribution from new and worn nozzles constructed with different materials and with different nominal flow rates.

	Nominal Flow Rate, L/min									
	0.8		1.5		2.3		3.0		MEAN	
NOZZLES*	New	Worn	New	Worn	New	Worn	New	Worn	New	Worn
Br	12.04	14.08	10.80	5.68	9.43	4.58	12.28	7.91	**11.14**	**8.06**
Ny	7.23	4.98	5.13	6.50	6.26	7.71	7.00	6.68	**6.41**	**6.46**
Pl	10.10	10.48	8.91	6.04	7.86	5.45	8.31	5.52	**8.80**	**6.87**
Ss	6.93	7.61	4.59	7.36	3.92	7.44	6.61	6.72	**5.51**	**7.28**
HSs	9.23	8.50	10.95	9.86	13.25	8.31	14.88	----	**12.08**	**8.89**

* Br= Brass, Ny= Nylon, Pl= Plastic, Ss= Stainless steel, HSs= Hardened stainless steel

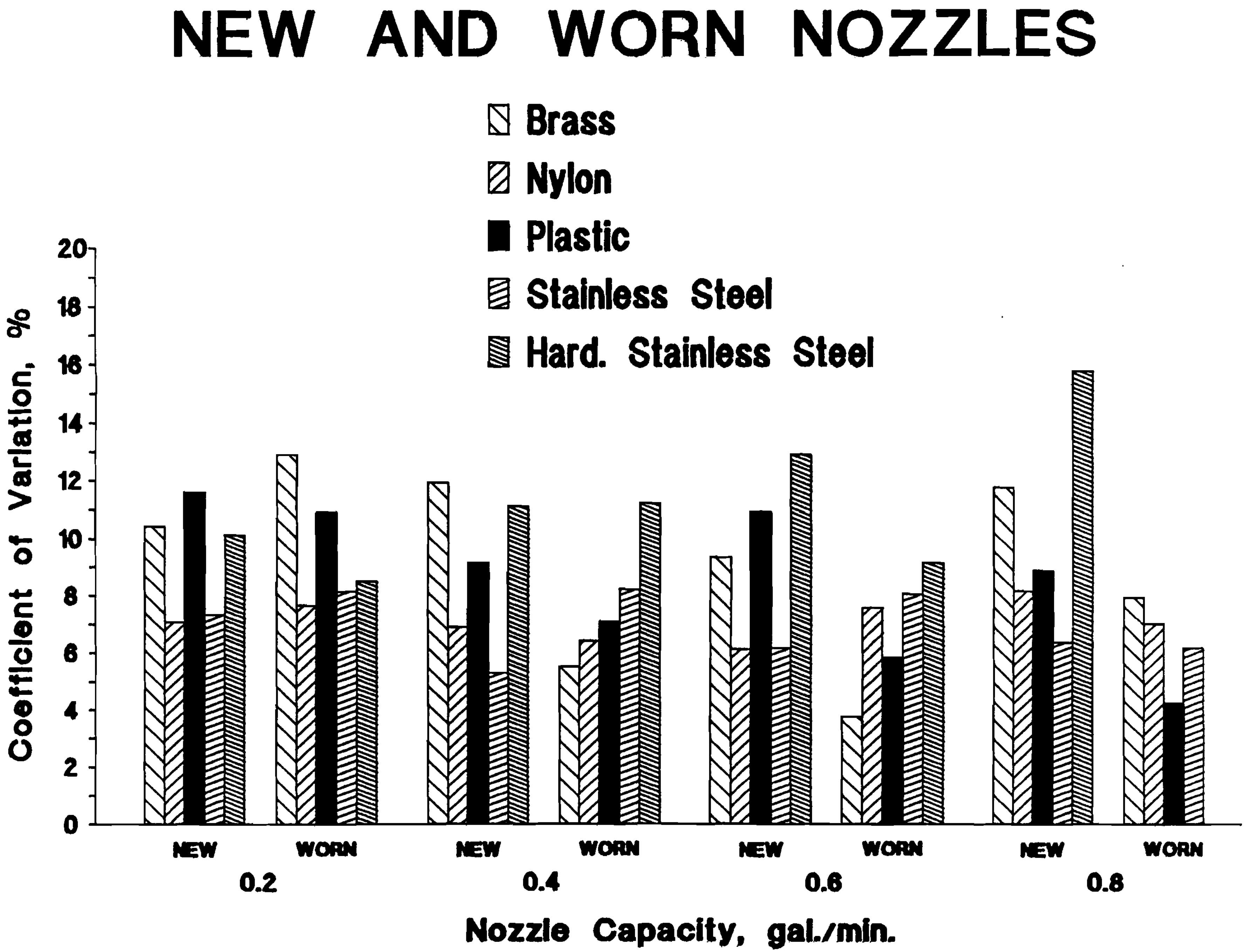


Figure 20. Graphical presentation of Coefficient of Variation values.

stainless steel and brass nozzles provided spray distributions with CV's higher than 10%. Of all the nozzles tested, the spray distribution with the highest CV (14.88%) was delivered by new hardened stainless steel nozzles with a nominal flow rate of 3.0 L/min (0.8 gpm).

The tests at various stages of wear provided expected results. As can be seen in Figure 21, the shape of the patterns changed as the nozzles wore but the width remained about the same. The most noticeable characteristic is that the volume of liquid increased near the center of the pattern as the nozzle wore. Again this seemed to support the conclusion that replacing the nozzles may not be necessary. Instead the operator may be able to just calibrate the nozzles and change the operating pressure, spacing, or boom height to compensate for the wear.

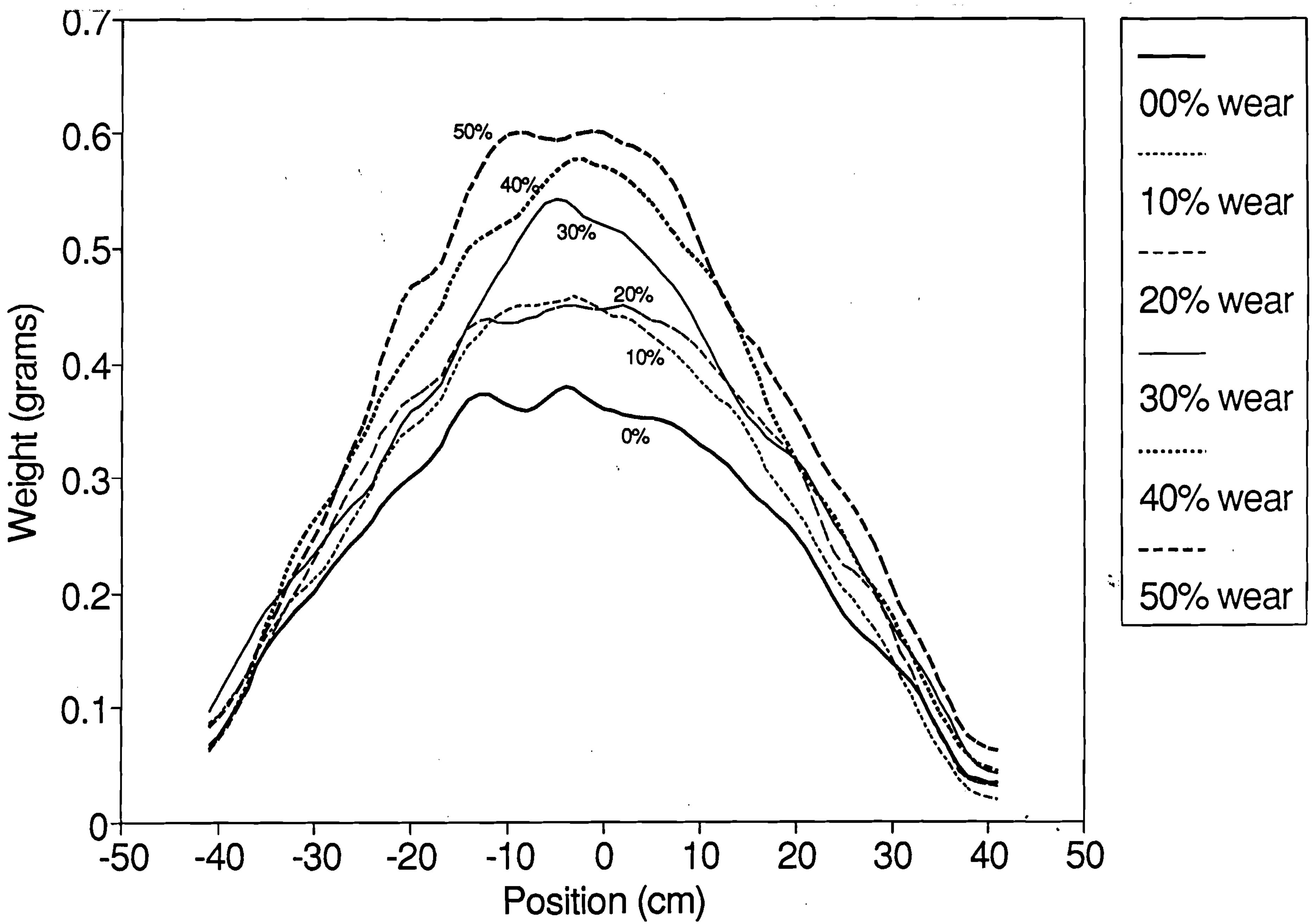


Figure 21. Spray distributions of new and 10, 20, 30, 40, and 50% worn Brass nozzles [Nominal Flow Rate: 0.8 L/min (0.2 gpm)].

CONCLUSIONS

1. Most of the patternators used currently to investigate spray pattern characteristics of nozzles are of the manual (conventional) type with graduated collection cylinders. Although these patternators provide educational demonstrations they are susceptible to human error during recording and analyzing data. This process is also labor intensive and time consuming. It took an average of 7 minutes (based on nine survey forms and the 2 patternator tests) or an average of 13 seconds per cylinder (based on seven survey forms and the two patternator tests) to collect data.
2. The new generation of patternators, used mostly by nozzle manufacturers, were more accurate and reliable than manual patternators. However, they are expensive, ranging in cost from $8,500 to $100,000, and may take up to 25 minutes to collect and analyze data for one test (reading 100 cylinders).
3. An automated single collection unit system was developed to measure and analyze spray distribution patterns of nozzles. It had a cost of about $4,500 and provided a more efficient and accurate means of data collection and analysis than manual patternators. The time for data collection took about 1 second per trough for one test trial of one nozzle. It took about 3 seconds per trough to complete three test trials of one nozzle and analyze this data. These benefits occurred because there was less manual labor and handling of the data.

4. The shapes of spray deposit patterns of new and worn fan pattern nozzles were different. The width of the spray patterns remained nearly constant but the volume of liquid collected in the center of the pattern of worn nozzles was slightly greater.
5. Manufacturers' recommendations for boom height and nozzle spacing for 80° flat fan nozzles resulted in distributions with CV's smaller than 15%. For seven of twenty new nozzles, the CV's exceeded 10%. Additional simulations of spray distributions with different boom heights and nozzle spacings are needed to determine the best combination of boom height and nozzle spacing for lowest CV of the distribution.
6. Some worn nozzles provided spray distributions with less variation than new nozzles.

RECOMMENDATIONS FOR FURTHER STUDY

1. A more in depth comparison of the results obtained with the new automated system to the results obtained with the conventional system should be conducted. This study would help to support the claim that this system's accuracy is acceptable.

2. Research should be under taken to develop a set of standards for spray nozzle testing. This will allow all of the researchers that are working in this area to be able to more readily compare their results.

3. An evaluation of the effect of the collection unit slot width and speed on CV may be helpful.

4. An investigation of various problems with the system should be conducted. One such problem may be excessive force recorded by the balance due to impact of droplets on the balance. Another problem is variations in speed of the collection unit probably caused by friction in the drive and guidance systems.

5. An evaluation of completely different patternator designs may produce an even better system for nozzle testing.

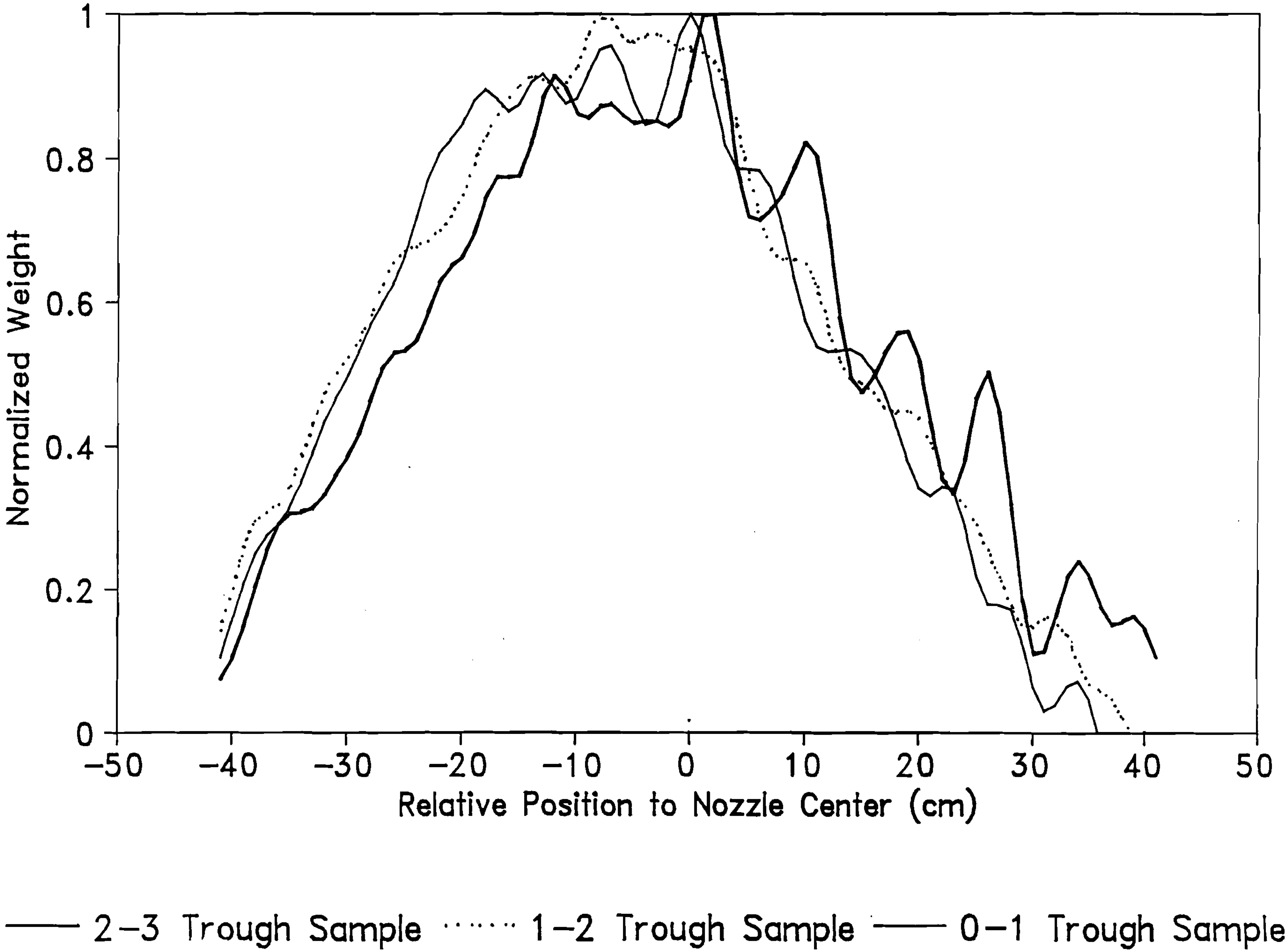
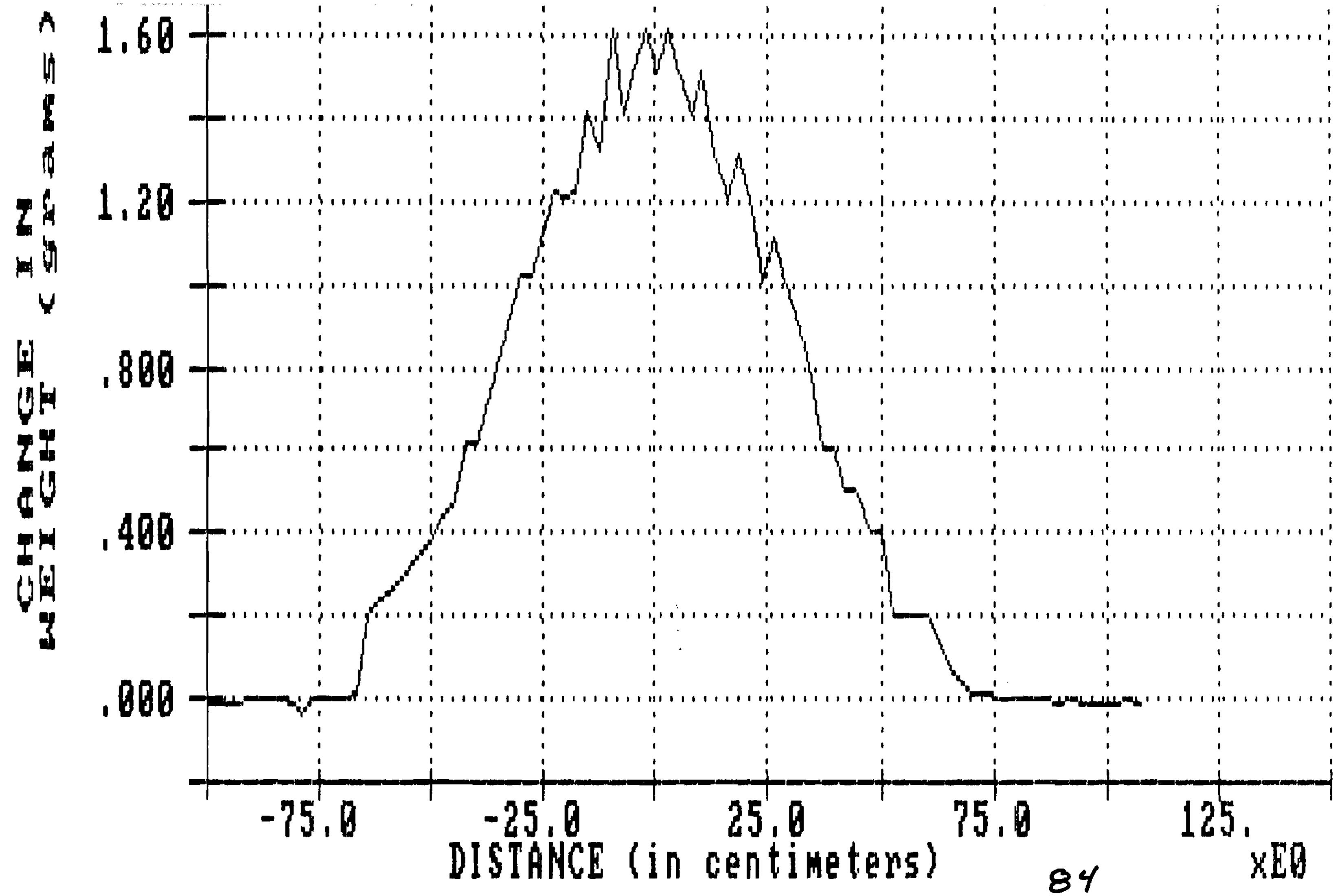


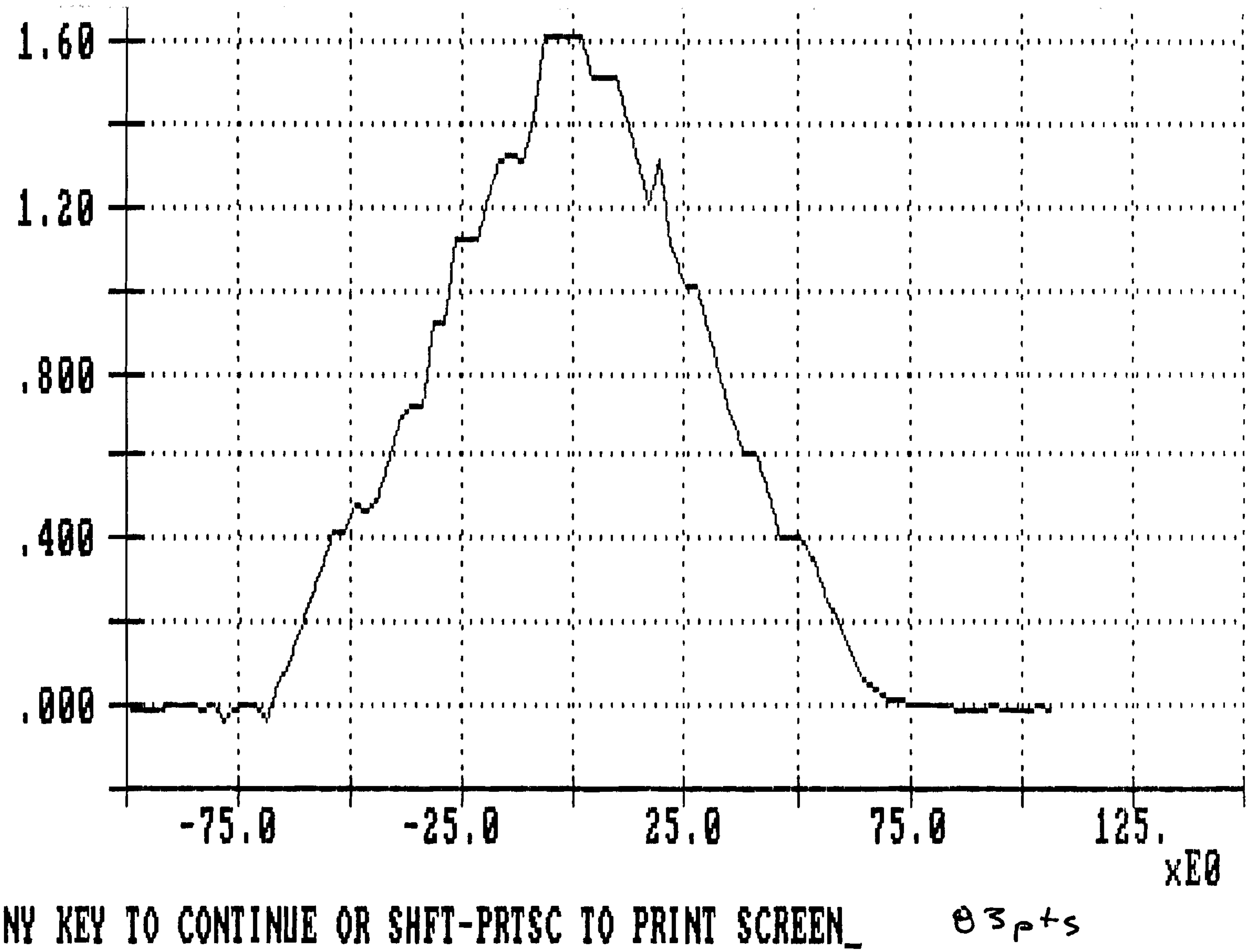
Figure 22. Effects of changing the size of the opening in the collection unit.



HIT ANY KEY TO CONTINUE OR SHFT-PRTSC TO PRINT SCREEN_ 84 ~~88~~ PTS

82190K.WK1 FINE UNSTABLE

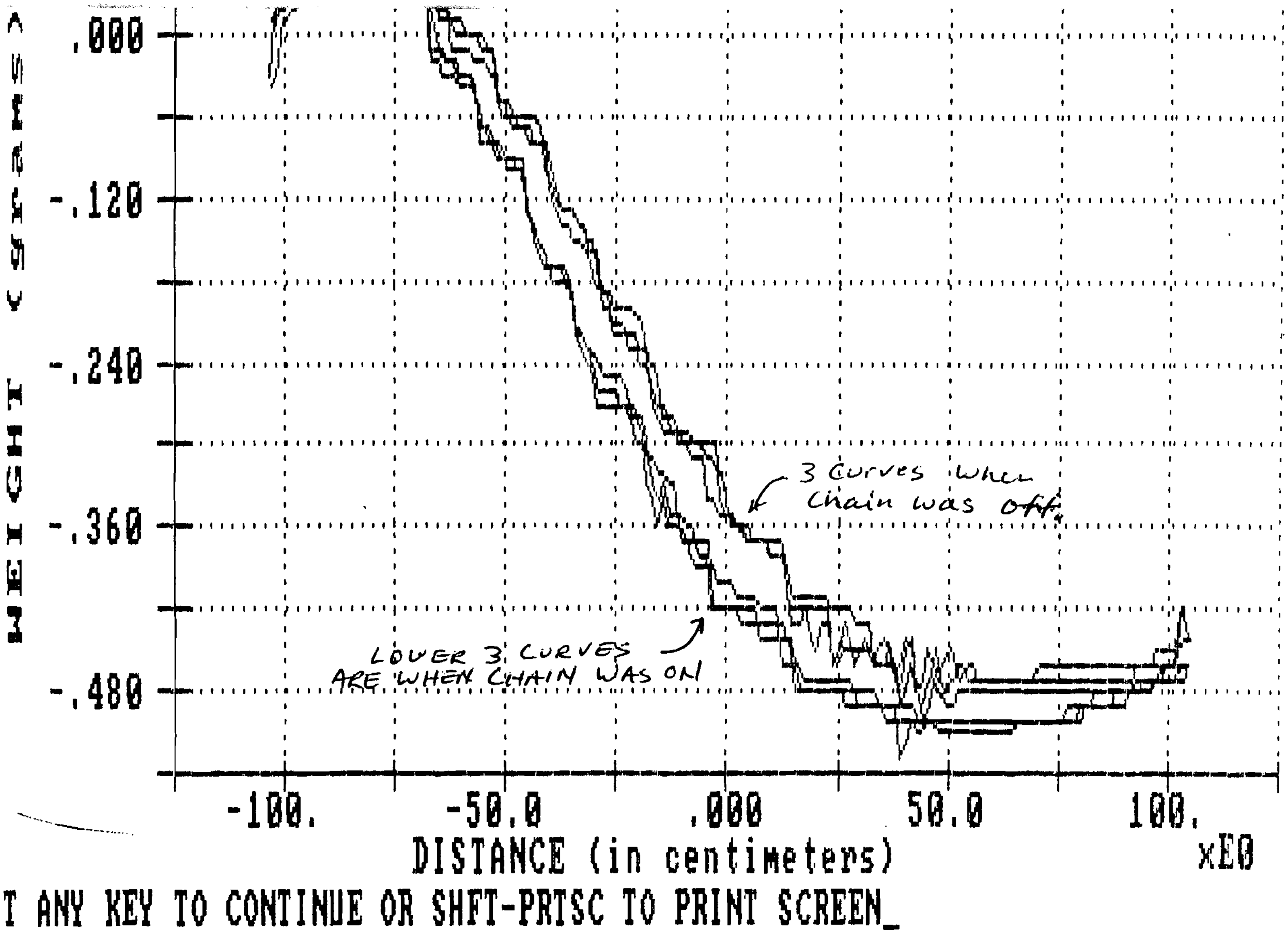
Figure 23. Effects of changing the operation mode of the balance. (Fine and Unstable modes)



83pts

82190N.WKI ANIMAL UNSTABLE

Figure 24. Effects of changing the operation mode of the balance. (Animal and Unstable modes)



8/9/90 Am SPEED: 33 CHAIN ON VS. CHAIN OFF LUBRICATED: 8/9/90 Am DRY RUN

Figure 25. Effects of different supports for the old final chain drive system.

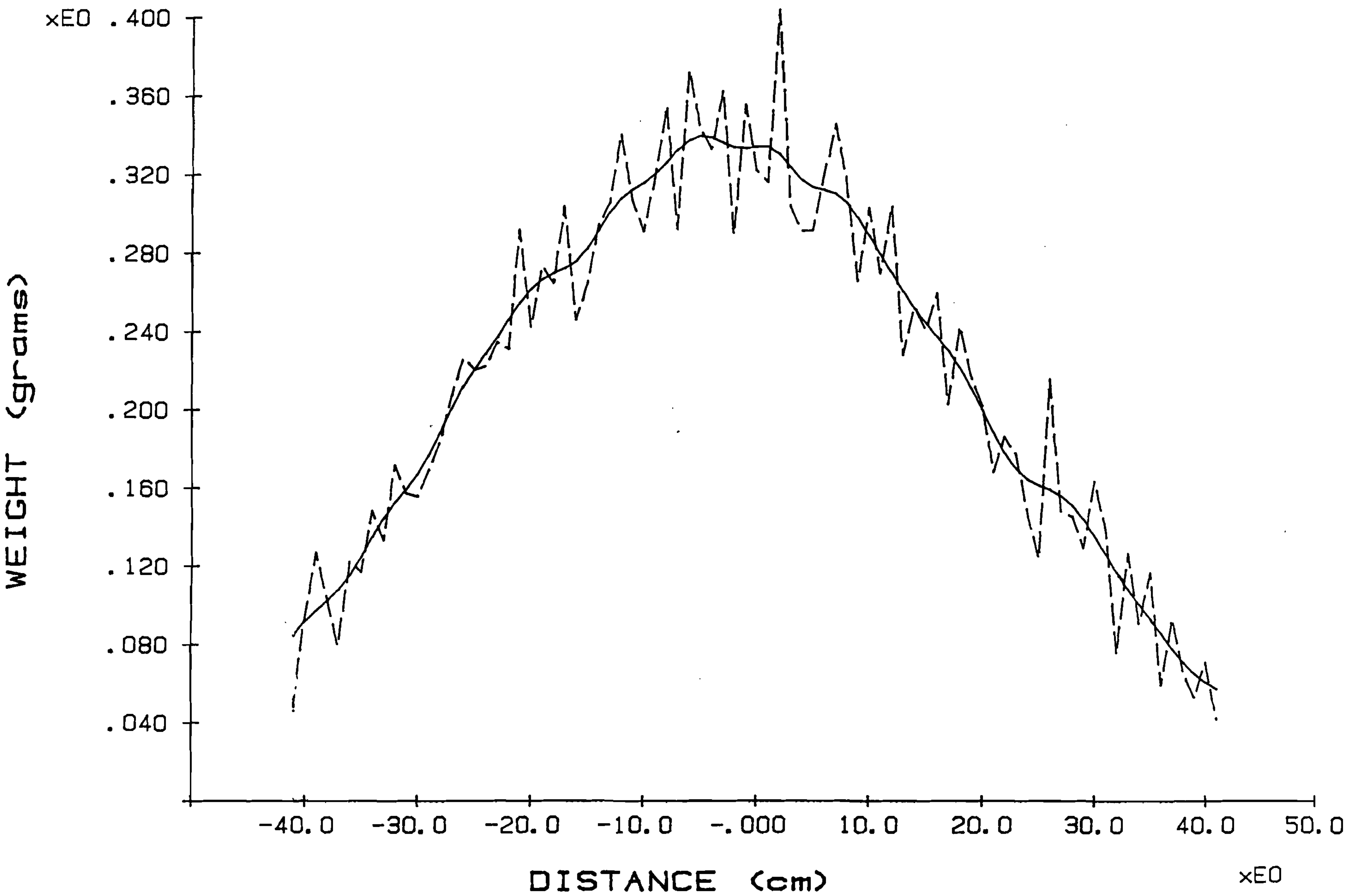


Figure 26. Effects of the ASYST smoothing routine on data.

—— Smooth & Avg COF = 1/4

– – – Just Avg

WTCAL.CRV


```
REAL DIM[ 868 ] ARRAY X
REAL DIM[ 868 ] ARRAY Y

CHDIR C:\ASYST\ASYSTDAT
" WTCAL.WK1"
DEFER> 123FILE.OPEN
5 1 868 1 123READ.RANGE
X 123FILE>ARRAY
5 2 868 1 123READ.RANGE
Y 123FILE>ARRAY
123FILE.CLOSE
CHDIR C:\ASYST

LOAD.OVERLAY MATFIT.SOV
STACK.CLEAR

  X Y 7 LEASTSQ.POLY.FIT
  CR ?
  CREATE.COPY CURVE7

CHDIR C:\ASYST\ASYSTDAT
123FILE.OPEN WTCAL.WK1
4 5 123WRITE.DOWN
" CURVE7" ">123FILE
5 5 123WRITE.DOWN
CURVE7 ARRAY>123FILE
123FILE.CLOSE
CHDIR C:\ASYST
```

```
O.OFF
////////////// DIMENSION ALL ARRAYS AND VARIABLES //////////////////
m[  500 , 13 ] string.array ASC.VALS

  STRING SCALING
  STRING SM?
  STRING ANS
  STRING FILENAME
  STRING COMMENT
  STRING NOZZLE_TYPE
  STRING NOZZLE_GPM
  STRING ERROR1L
  STRING ERROR2L
  STRING CV1L
  STRING CV2L
  STRING SD1L
  STRING SD2L
  STRING AVG1L
  STRING SPACINGL
  STRING AVG2L

KEN DIST1
KEN WT
KEN WT2
KEN DIST2
KEN WTCAL
KEN CV.DIST
KEN AVG.DIST
KEN AVG.WT1
KEN AVG.WT2
KEN BOOM1
KEN BOOM2
KEN NOZ0
KEN NOZ1
KEN NOZ2
KEN NOZ3
KEN NOZ4
KEN NOZ5
KEN DISTANCE1
KEN DISTANCE2
KEN WEIGHT1
KEN WEIGHT2

EGER DIM[ 500 ]  array DIST
     DIM[ 83  ]  ARRAY POSIT1

     SCALAR ANSWER2
     SCALAR RSPNS
     SCALAR NTRIALS
     SCALAR WTRIALS
     SCALAR NOZZLE
     SCALAR ITER
     SCALAR ELEM0 SCALAR ELEM1 SCALAR ELEM2 SCALAR ELEM3 SCALAR ELEM4
     SCALAR DIM1


ST Version 3.10
e 1    SUPER2.   02/17/92   21:41:20.10
```

```
      SCALAR TESTS
      SCALAR SPACING

L SCALAR AVG1  SCALAR AVG2  SCALAR ST.DEV1  SCALAR CV1
  SCALAR ST.DEV2  SCALAR CV2
  SCALAR NOZZLE_GPM#
  SCALAR VOLTS
  SCALAR COUNT
  SCALAR ANSWER
  SCALAR ERROR1S
  SCALAR ERROR2S

  DIM[ 1 ] ARRAY #COUNT
  DIM[ 1 ] ARRAY #COUNT1
  DIM[ 1 ] ARRAY #COUNT2
  DIM[ 1 ] ARRAY AVG
  DIM[ 1 ] ARRAY ST.DEV
  DIM[ 1 ] ARRAY CV
  DIM[ 1 ] ARRAY ERR
  DIM[ 2 ] ARRAY AB1
  DIM[ 2 ] ARRAY AB2
  DIM[ 84 ] ARRAY AVGD.WT1
  DIM[ 83 ] ARRAY sm.wt1
  DIM[ 83 ] ARRAY sm.wt2
  DIM[ 84 ] ARRAY AVGD.WT2
  DIM[ 84 ] ARRAY ERROR1
  DIM[ 84 ] ARRAY ERROR2
  DIM[ 84 ] ARRAY SMD.WT1
  DIM[ 84 ] ARRAY SMD.WT2

 41 POSIT1 []FILL
///////////////////////////////////////////////////////////////////

I-820                                           \ SET UP A/D TEMPLATE
1 A/D.TEMPLATE DEMO.TEMPLATE
D.INIT

6 RS232.DEVICE HPPLOTTER
0 SET.BAUD
ET.PARITY
ET.DATA.BITS
ET.STOP.BITS
32.POL.MODE
.OFF

ET.DATA
: "INPUT
LENAME ":=
LENAME
FER> 123FILE.OPEN
1 1 1 123READ.RANGE
OUNT 123FILE>ARRAY
OUNT [ 1 ] COUNT :=
ITEGER DIM[ COUNT ] UNNAMED.ARRAY


ST Version 3.10
e 2    SUPER2.   02/17/92   21:41:22.24
```

```
OVER := BECOMES> DIST2
AL DIM[ COUNT ] UNNAMED.ARRAY
OVER := BECOMES> WT2
1 COUNT 1 123READ.RANGE
ST2 123FILE>ARRAY
2 COUNT 1 123READ.RANGE
2 123FILE>ARRAY
3FILE.CLOSE
DIR C:\ASYST



T2
REEN.CLEAR
GIN
 CR ." Do you want to:    (1) Load data from a disk,                  or"
 CR ."                    (2) Collect data from nozzle(s),            or"
 CR ."                    (3) Continue (use data already loaded in). "  CR
 #INPUT RSPNS :=
 RSPNS 1 >= RSPNS 3 <= AND
TIL

PNS 3 <>

  STACK.CLEAR
  1 ITER :=        0 DIST :=       0 AVGD.WT1 :=   0 AVGD.WT2 :=
  0 ERROR1 :=      0 ERROR2 :=     0 ERROR1S :=    0 ERROR2S :=
  0 COUNT :=       0 #COUNT :=     0 #COUNT1 :=    0 #COUNT2 :=
  0 AVG1 :=        0 AVG2 :=       0 ST.DEV1 :=    0 ST.DEV2 :=
  0 CV1 :=         0 CV2 :=        0 AVG :=        0 ST.DEV :=
  0 ERR :=         0 CV :=         0 sm.wt1 :=     0 sm.wt2 :=
  0 SMD.WT1 :=     0 SMD.WT2 :=

  INTEGER DIM[ 1 ] UNNAMED.ARRAY 0 OVER := DUP 2 *DUP 4 *DUP 5 *DUP
  BECOMES> WEIGHT2   BECOMES> WEIGHT1  BECOMES> DISTANCE1
  BECOMES> DISTANCE2 BECOMES> DIST1    BECOMES> WT
  BECOMES> WT2       BECOMES> DIST2    BECOMES> WTCAL
  BECOMES> CV.DIST   BECOMES> AVG.DIST BECOMES> AVG.WT1 BECOMES> AVG.WT2

  " 0" ERROR1L ":=  " 0" ERROR2L ":=  " 0" AVG1L ":=  " 0" AVG2L ":=
  " 0" CV1L ":=     " 0" CV2L ":=     " 0" SD1L ":=   " 0" SD2L ":=
EN

TESTS :=
PNS 1 = RSPNS 2 = OR

 CR ." How many NEW nozzle tests will you perform or load in? "
 #INPUT NTRIALS :=
 CR ." How many WORN nozzle tests will you perform or load in? "
 #INPUT WTRIALS :=
EN
PNS 1 =

 NTRIALS 0 >


ST Version 3.10
e 3    SUPER2.   02/17/92   21:41:25.04
```

```
IF
    1 ITER :=
    SCREEN.CLEAR
    CR ." FOR THE" NTRIALS . ." NEW NOZZLE TRIAL(S)"
    CR ." ENTER FILENAME & PATH FOR NEW NOZZLE NUMBER " ITER .
    GET.DATA

    INTEGER DIM[ COUNT ] UNNAMED.ARRAY
    0 OVER := BECOMES> DISTANCE1
    REAL DIM[ COUNT ] UNNAMED.ARRAY
    0 OVER := BECOMES> WEIGHT1
    WT2 WEIGHT1 :=
    DIST2 DISTANCE1 :=
    COUNT #COUNT [ 1 ] :=
    #COUNT #COUNT1 + #COUNT1 :=
    ITER 1 + ITER :=
    1000 800 TUNE
THEN

NTRIALS 1 >
IF
    BEGIN
        CR ." ENTER FILENAME & PATH FOR NEW NOZZLE NUMBER " ITER .
        GET.DATA

        DISTANCE1 DIST2 CATENATE
        BECOMES> DISTANCE1

        WEIGHT1 WT2 CATENATE
        BECOMES> WEIGHT1

        COUNT #COUNT [ 1 ] :=
        #COUNT #COUNT1 + #COUNT1 :=
        ITER 1 + ITER :=
        1000 800 TUNE
        ITER NTRIALS 1 + =
    UNTIL
THEN

WTRIALS 0 >
IF
    SCREEN.CLEAR
    CR ." FOR THE" WTRIALS . ." WORN NOZZLE TRIAL(S)"
    CR ." ENTER FILENAME & PATH FOR WORN NOZZLE NUMBER " ITER .
    GET.DATA

    REAL DIM[ COUNT ] UNNAMED.ARRAY
    0 OVER := BECOMES> WEIGHT2
    INTEGER DIM[ COUNT ] UNNAMED.ARRAY
    0 OVER := BECOMES> DISTANCE2
    WT2 WEIGHT2 :=
    DIST2 DISTANCE2 :=
    COUNT #COUNT [ 1 ] :=
    #COUNT #COUNT2 + #COUNT2 :=
```

```
     ITER 1 + ITER :=
     1000 800 TUNE
 THEN

 WTRIALS 1 >
 IF
     BEGIN
         CR ." ENTER FILENAME & PATH FOR WORN NOZZLE NUMBER " ITER .
         GET.DATA

         DISTANCE2 DIST2 CATENATE
         BECOMES> DISTANCE2

         WEIGHT2 WT2 CATENATE
         BECOMES> WEIGHT2

         COUNT #COUNT [ 1 ] :=
         #COUNT #COUNT2 + #COUNT2 :=
         ITER 1 + ITER :=
         1000 800 TUNE
     ITER NTRIALS WTRIALS + 1 + =
     UNTIL
 THEN
EN


16 RS232.DEVICE BALANCE                          \ SET UP RS232 COMMUNICATION
00 SET.BAUD
   SET.PARITY
   SET.DATA.BITS
   SET.STOP.BITS
232.POL.MODE
R.OFF
C.VALS "RS232.RCV.BUFFER

TART.MSG
S232.RCV.RESET
DIST :=
REEN.CLEAR
     MAKE SURE THE LEFT SIDE OF THE BALANCE HOUSING IS EVEN WITH THE" CR
 LEFT UPRIGHT FRAME PIECE IE. EXTEND THE CABLE 10 CM (4 INCHES).  " CR
 THEN SET THE MOTOR SPEED.  WHEN YOU ARE READY PRESS <RETURN> AND START "

 THE MOTOR SOON AFTER THAT SO THE BALANCE WILL STILL BE AT ZERO WHEN IT "

 STARTS."
KEY DROP ?DROP CR
REEN.CLEAR
 CR CR CR CR CR ."                    GATHERING DATA..."


EADY                                           \ PRINTS "READY" ON BALANCE SCREEN
LANCE
D READY"


ST Version 3.10
e 5     SUPER2.    02/17/92    21:41:29.77
```

```
3 ASCII" "CAT
0 ASCII" "CAT
RS232.OUT
CII D RS232.OUT                              \ CLEAR BALANCES SCREEN
 RS232.OUT                                          \ CARRIAGE RETURN
 RS232.OUT                                          \ LINE FEED


ARE
ALANCE                                       \ SENDS A "T" TO THE BALANCE
 T"                                          \ THIS IS THE COMMAND TO TARE IT
3 ASCII" "CAT
0 ASCII" "CAT
RS232.OUT


SIR                                           \ SENDS A "SI" TO THE BALANCE
LANCE
CII S RS232.OUT                              \ THIS IS THE COMMAND WHICH PUTS
CII I RS232.OUT                             \ THE BALANCE IN THE SEND THE NEXT
CII R RS232.OUT
 RS232.OUT                                   \ AVAILABLE WEIGHT MODE.
 RS232.OUT


REAL DIM[ 7 ] ARRAY CURVE6                   \ LOAD IN THE COEFFICIENTS FOR
REAL DIM[ 8 ] ARRAY CURVE7                   \ LOAD IN THE COEFFICIENTS FOR

OAD.POLYS
DIR C:\ASYST\ASYSTDAT                        \ THE 7th ORDER POLYNOMIAL CALLED
3FILE.OPEN C:\ASYST\ASYSTDAT\POLYCURV.WK1  \ CURVE7 FROM A LOTUS 123 FILE
 2 8 1 123READ.RANGE
RVE7 123FILE>ARRAY
3FILE.CLOSE
3FILE.OPEN WTCAL.WK1                         \ THE 6th ORDER POLYNOMIAL CALLED
4 7 1 123READ.RANGE                          \ CURVE6 FROM A LOTUS 123 FILE
RVE6 123FILE>ARRAY
3FILE.CLOSE
DIR C:\ASYST



ET.POSITION
 DEMO.TEMPLATE
 A/D.IN                               \ INPUT FROM DATA AQUISTION BOARD
 -5. 5. A/D.SCALE                     \ CONVERT STEPS TO VOLTS
 VOLTS :=
 .0066 4.98 *                         \ CONVERT VOLTS TO INCHES AND
 VOLTS SWAP / 2.54 *                  \ THEN TO CENTIMETERS
 CURVE7 POLY[X]                       \ MAKE APPROXIMATIONS USING POLYNOMIAL
 134.35 -                             \ FINAL MOST ACCURATE POSITION
 \ ? CR                    \ PRINTING WILL CONSIDERABLEY SLOW DATA COLLECTION
```

```
GET
R                                      \ EXECUTE COLON DEF SIR

GIN
 STACK.CLEAR
 GET.POSITION                          \ EXECUTE COLON DEF. GET.POSITION
 DIST [ 1 ] :=                         \ DIST = THE POSITION VALUE
 DIST [ 1 ]
 -105. >=                             \ TRUE IF THE POSITION IS > OR = -105 CM
TIL                                    \ IF TRUE CONTINUE IF FALSE GOTO BEGIN
 STACK.CLEAR
COUNT :=                               \ INITIATE A COUNTER VARIABLE
GIN
     COUNT 1 + COUNT :=                \ INCREMENT THE COUNTER VARIABLE BY 1
 RS232>BUFFER                          \ INPUT FROM RS232 CABLE
 GET.POSITION                          \ EXECUTE COLON DEF. GET.POSITION
 DIST [ COUNT ] :=                     \ DIST = THE POSITION VALUE
 DIST [ COUNT ]
 105. >=                               \ TRUE IF THE POSITION IS > OR = 105 CM
 COUNT 500. =                          \ TRUE IF THE COUNTER IS = 500
 OR                                    \ TRUE IF EITHER OF THE 2 ABOVE IS TRUE
TIL                                    \ IF TRUE CONTINUE, IF NOT GOTO BEGIN
REEN.CLEAR
 CR CR CR CR CR ."                 ...FINISHED GATHERING DATA!"
0 1040 TUNE
0 840 TUNE
ACK.CLEAR


RANS                                   \ PUTS THE ONLY THOSE ELEMENTS OF THE
 COUNT 1 + 1 DO                        \ ARRAY DIST THAT ARE FILLED WITH DATA
 DIST [ I ]                            \ INTO THE ARRAY DIST1
 DIST1 [ I ] :=
 LOOP


UMB                                    \ EXTRACTS ONLY THE NUMBER PORTION OF
 COUNT 1 + 1 DO                        \ THE STRING ARRAY ASC.VALS AND PLACES
 ASC.VALS                              \ THESE NUMBERS IN THE ARRAY WT.
 "[ I ] 0 "NUMBER ?DROP "DROP          \ ?
 WT [ I ] :=
 LOOP


UBTRACT.WTCAL.CRV                      \ SUBTRACTS THE WEIGHT CALIBRATION
 DIST1 CURVE6 POLY[X]                  \ CURVE FROM THE WEIGHT READ VIA RS232
 WTCAL :=
 WT WTCAL -
 WT :=


CHG                                    \ FINDS THE DIFFERENCE IN WEIGHT
UNT 1 DO                               \ BETWEEN EACH ELEMENT OF THE ARRAY WT
 [ I 1 + ] WT [ I ] -                  \ AND TURNS DIST1 INTO DIST2 WHICH MUST
```

```
2 [ I ] :=                                  \ HAVE AN EQUAL NUMBER OF ELEMENTS TO WT
ST1 [ I 1 + ]                                \ TO BE PLOTTED WITH WT.
ST2 [ I ] :=
OP


ET.FILENAME&COMMENT
 ." Enter device, path, and filename (EX. C:\asyst\asystdat\072690A.WK1) _"
 ." for saving the data arrays." CR "INPUT
LENAME ":=
 ." Enter a comment for the data file (max. 70 characters).                _"

NPUT COMMENT ":=


RAPH1
F.VUPORT NORMAL.COORDS
ST1

.AUTO.PLOT
RMAL.COORDS
 LABEL.DIR
 CHAR.DIR
25 .37 POSITION  " WEIGHT (grams)" CENTERED.LABEL
LABEL.DIR
CHAR.DIR
 .068 POSITION " DISTANCE (in centimeters)" CENTERED.LABEL
2 .95 POSITION " CUMULATIVE SPRAY" CENTERED.LABEL
2 .88 POSITION " NOZZLE DISTRIBUTION" CENTERED.LABEL
RSOR.OFF CR
LENAME "TYPE ."     DATA PTS=" COUNT . CR
MMENT "TYPE
KEY DROP ?DROP


RAPH2
F.VUPORT NORMAL.COORDS
ST2
2
.AUTO.PLOT
RMAL.COORDS
 LABEL.DIR
 CHAR.DIR
28 .37 POSITION  " WEIGHT (grams)" CENTERED.LABEL
13 .37 POSITION  " CHANGE IN" CENTERED.LABEL
LABEL.DIR
CHAR.DIR
 .068 POSITION " DISTANCE (in centimeters)" CENTERED.LABEL
 .95 POSITION " SPRAY NOZZLE" CENTERED.LABEL CR
 .88 POSITION " DISTRIBUTION" CENTERED.LABEL CR
LENAME "TYPE ."     DATA PTS=" COUNT .  CR
MMENT "TYPE
KEY DROP ?DROP


ST Version 3.10
e 8    SUPER2.   02/17/92   21:41:39.27
```

```
AVE.OR.EXIT?                                   \ SAVES DATA OR EXITS THE PROGRAM
 ENTER A... (1) to SAVE the data and CONTINUE " CR
            (2) to SAVE the data and EXIT " CR
            (3) to EXIT without saving the data" CR
            (4) to CONTINUE without saving the data." CR
NPUT ANSWER :=
SWER 1 >
SWER 4 < AND

TER NTRIALS WTRIALS + <
F
 CR ." ARE YOU SURE YOU WANT TO EXIT ?? 2=YES 1=NO  "
 #INPUT
 2 <>
 IF
   1 ANSWER :=
 THEN
HEN
N
SWER 3. <>
SWER 4. <> AND

TER  1  =
TRIALS 0 > AND
F
 COUNT #COUNT [ 1 ] :=
 #COUNT #COUNT1 + #COUNT1 :=

 INTEGER DIM[ COUNT 1 - ] UNNAMED.ARRAY
 0 OVER := BECOMES> DISTANCE1
 INTEGER DIM[ COUNT 1 - ] UNNAMED.ARRAY
 0 OVER := BECOMES> WEIGHT1
 WT2 WEIGHT1 :=
 DIST2 DISTANCE1 :=
HEN

TER 1 >
TER NTRIALS 1 + < AND
F
 COUNT #COUNT [ 1 ] :=
 #COUNT #COUNT1 + #COUNT1 :=

 DISTANCE1 DIST2 CATENATE
 BECOMES> DISTANCE1

 WEIGHT1 WT2 CATENATE
 BECOMES> WEIGHT1

HEN

TER NTRIALS 1 + =


ST Version 3.10
e 9    SUPER2.   02/17/92   21:41:41.19
```

```
TRIALS 0 > AND
F
 COUNT #COUNT [ 1 ] :=
 #COUNT #COUNT2 + #COUNT2 :=

 INTEGER DIM[ COUNT 1 - ] UNNAMED.ARRAY
 0 OVER := BECOMES> WEIGHT2
 INTEGER DIM[ COUNT 1 - ] UNNAMED.ARRAY
 0 OVER := BECOMES> DISTANCE2
 WT2 WEIGHT2 :=
 DIST2 DISTANCE2 :=
HEN

TER NTRIALS 1 + >
TER NTRIALS WTRIALS + 1 + < AND
F
 COUNT #COUNT [ 1 ] :=
 #COUNT #COUNT2 + #COUNT2 :=

 DISTANCE2 DIST2 CATENATE
 BECOMES> DISTANCE2

 WEIGHT2 WT2 CATENATE
 BECOMES> WEIGHT2

HEN
LENAME DEFER> 123FILE.CREATE
LENAME DEFER> 123FILE.OPEN
1 123WRITE.DOWN
LENAME ">123FILE
1 123WRITE.DOWN
MMENT ">123FILE
1 123WRITE.DOWN
UNT #COUNT [ 1 ] :=
OUNT ARRAY>123FILE
2 123WRITE.DOWN
WT" ">123FILE
2 123WRITE.DOWN
 ARRAY>123FILE
1 123WRITE.DOWN
DIST1" ">123FILE
1 123WRITE.DOWN
ST1 ARRAY>123FILE
5 123WRITE.DOWN
WT2" ">123FILE
5 123WRITE.DOWN
2 ARRAY>123FILE
4 123WRITE.DOWN
DIST2" ">123FILE
4 123WRITE.DOWN
ST2 ARRAY>123FILE
ER NTRIALS WTRIALS + 1 + >

 4 7 123WRITE.DOWN


ST Version 3.10
e 10     SUPER2.   02/17/92   21:41:43.06
```

```
 " MEAN" ")123FILE
 5 7 123WRITE.DOWN
 AVG ARRAY>123FILE
 7 7 123WRITE.DOWN
 " ST. DEV." ")123FILE
 8 7 123WRITE.DOWN
 ST.DEV ARRAY>123FILE
 10 7 123WRITE.DOWN
 " % C.V." ")123FILE
 11 7 123WRITE.DOWN
 CV ARRAY>123FILE
 13 7 123WRITE.DOWN
 " % ERROR" ")123FILE
 15 7 123WRITE.DOWN
 ERR ARRAY>123FILE
EN
3FILE.CLOSE
DIR C:\ASYST
ER 1 + ITER :=
N


 \ \ \ \ \ \ \ \ \ \ \ \ \ PROGRAM \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ 
D.POLYS

D
IN

ART.MSG

ADY                                      \ EXECUTE COLON DEF.  READY

RE                                       \ EXECUTE COLON DEF.  TARE

T                                        \ EXECUTE COLON DEF.  GET

TEGER  dim[  COUNT ]  UNNAMED.array          \ DIMENSION ARRAYS FOR THE EXACT
over := BECOMES> DIST1
AL  dim[  COUNT ]  UNNAMED.array           \ NUMBER (COUNT) OF DATA POINTS
over := BECOMES> WT
AL  dim[  COUNT ]  UNNAMED.array
over := BECOMES> WTCAL
AL  dim[  COUNT 1 - ]  UNNAMED.array
over := BECOMES> WT2
TEGER  dim[  COUNT 1 - ]  UNNAMED.array
over := BECOMES> DIST2

ANS                                          \ EXECUTE COLON DEF.  TRANS

MB                                           \ EXECUTE COLON DEF.  NUMB
ACK.CLEAR
BTRACT.WTCAL.CRV                      \ EXE.  COLON DEF.   SUBTRACT.WTCAL.CRV
ACK.CLEAR
```

```
T.FILENAME&COMMENT
IS.DEFAULTS
APH1
 ." Do you want to plot this graph?"
 ."         (Y)es or (N)o "  CR
NPUT ANS ":=
RMAL.DISPLAY
Y" ANS "=
y" ANS "= OR
                                          \ PLOT IF USER ANSWERS YES
R CR CR CR CR CR CR ."                    PLOTTING..."
PPLOTTER                                  \ MAKE PLOTTER CURRENT RS232 DEVICE
LOTTER.DEFAULTS
P7470
RAPH1
BM.GRAPHICS
ORMAL.DISPLAY
EN
HG
ACK.CLEAR
APH2                                      \ EXECUTE COLON DEF. GRAPH2
 ." Do you want to plot this graph?"
 ."         (Y)es or (N)o "  CR
NPUT ANS ":=
RMAL.DISPLAY
Y" ANS "=
y" ANS "= OR
                                          \ PLOT IF USER ANSWERS YES
R CR CR CR CR CR CR ."                    PLOTTING..."
LOTTER.DEFAULTS
P7470
RAPH2
BM.GRAPHICS
ORMAL.DISPLAY
ALANCE                                    \ MAKE BALANCE CURRENT RS232 DEVICE
EN
VE.OR.EXIT?                               \ EXECUTE COLON DEF SAVE.OR.EXIT?

ER NTRIALS WTRIALS + 1 + )=
SWER 2. =  OR                             \ TRUE IF ANSWER = 2 OR IF
SWER 3. =  OR                             \ ANSWER = 3

IL                                        \ IF TRUE CONTINUES IF FALSE GOES
                                          \ TO BEGIN AGAIN.

ORTER                             \ SORTS DISTANCE1, WEIGHT1, DISTANCE2,
CREEN.CLEAR CR ." SORTING..."
TRIALS 0 >
F
   DISTANCE1 SORT&INDEX                 \ AND WEIGHT2 IN ASCENDING ORDER BY
   SWAP DISTANCE1 :=                    \ THE DISTANCE ARRAY
   WEIGHT1 SWAP LOOKUP
   WEIGHT1 :=
HEN
```

```
TACK.CLEAR
TRIALS 0 >
=
   DISTANCE2 SORT&INDEX
   SWAP DISTANCE2 :=
   WEIGHT2 SWAP LOOKUP
   WEIGHT2 :=
HEN


VRG
RIALS 0 >

  SCREEN.CLEAR CR ." AVERAGING NEW NOZZLE WEIGHTS...."
  85 1 DO
    I 43 - DISTANCE1 [=] DUP               \ SEARCHES THE DISTANCE ARRAY FOR
    []MAX 0 =
    IF
        1000 840 TUNE
        CR ." There is no NEW (unworn) data at" I 43 - . ." cm."
    THEN
    DUP []MAX 1 =
    IF
        TRUE.INDICES                         \ FOR ANY DUPLICATE NUMBERS AND
        WEIGHT1 SWAP LOOKUP DUP MEAN         \ THEN AVERAGES THE WEIGHTS WHICH
        AVGD.WT1 [ I ] :=                    \ CORRESPOND TO THESE DUPLICATE
        INDEX.ARRAY SWAP []MAX 1 >
        IF
             SAMPLE.VARIANCE SQRT            \ DISTANCES & CREATES 2 NEW ARRAYS
             AVGD.WT1 [ I ] / 100 *    \ WITH NO DUPLICATIONS USING THE AVGS
             ERROR1 [ I ] :=
        THEN
     THEN
     STACK.CLEAR
  LOOP
  ERROR1 MEAN ERROR1S :=
EN

RIALS 0 >

  SCREEN.CLEAR CR ." AVERAGING WORN NOZZLE WEIGHTS...."
  85 1 DO
    I 43 - DISTANCE2 [=] DUP               \ DOES THE SAME FOR THE WORN NOZZLE
    []MAX 0 =
    IF
        1000 840 TUNE
        CR ." There is no WORN data at" I 43 - . ." cm."
    THEN
    DUP []MAX 1 =
    IF
        TRUE.INDICES                           \ DATA
        WEIGHT2 SWAP LOOKUP DUP MEAN
        AVGD.WT2 [ I ] :=
        INDEX.ARRAY SWAP []MAX 1 >


ST Version 3.10
e 13     SUPER2.    02/17/92    21:41:51.30
```

```
        IF
              SAMPLE.VARIANCE SQRT
              AVGD.WT2 [ I ] / 100 *
              ERROR2 [ I ] :=
        THEN
    THEN
    STACK.CLEAR
  LOOP
  ERROR2 MEAN ERROR2S :=
EN


MOOTHER
TRIALS 0 >
F
   CR ." Do you want to smooth the NEW nozzle data?"
   CR ."    (Y)es    or     (N)o"
   CR "INPUT SM? ":=
   " N" SM? "=
   " n" SM? "= OR NOT
   IF
       SCREEN.CLEAR CR ." SMOOTHING NEW NOZZLE WEIGHTS..."
       1. 3.5 / set.cutoff.freq        \ SMOOTHS THE NOISE FROM THE WEIGHT
       AVGD.WT1 smooth SMD.WT1 :=      \ DATA BY AVGING ANY FREQUENCIES
   THEN
HEN
TRIALS 0 >
F
   CR ." Do you want to smooth the WORN nozzle data?"
   CR ."    (Y)es    or     (N)o"
   CR "INPUT SM? ":=
   " N" SM? "=
   " n" SM? "= OR NOT
   IF
       SCREEN.CLEAR CR ." SMOOTHING WORN NOZZLE WEIGHTS..."
       1. 3.5 / set.cutoff.freq               \ WHICH OCCUR W/IN 3.5 CM
       AVGD.WT2 smooth SMD.WT2 :=
   THEN
HEN


CHG2
 1 DO
 NTRIALS 0 >
 IF
     SMD.WT1 [ I 1 + ] SMD.WT1 [ I ] -
     sm.wt1 [ I ] :=
 THEN
 WTRIALS 0 >
 IF
     SMD.WT2 [ I 1 + ] SMD.WT2 [ I ] -
     sm.wt2 [ I ] :=
 THEN
OP


ST Version 3.10
e 14    SUPER2.   02/17/92   21:41:53.55
```

```
.V.1
ACK.CLEAR
3IN
 SCREEN.CLEAR
 CR ." Enter nozzle spacing in centimeters as a whole number"
 CR ." (integer) value. (Must be between 21 and 82 cm)        "
 #INPUT SPACING :=
PACING 21 >=
PACING 82 <= AND
TIL

ACING -1 * 41 -   ELEM0 :=
ACING      41 -   ELEM1 :=
ACING  2 * 41 -   ELEM2 :=
ACING  3 * 41 -   ELEM3 :=
ACING  4 * 41 -   ELEM4 :=
ACING  3 *  1 +    DIM1 :=

TEGER DIM[ DIM1 ] UNNAMED.ARRAY DUP
      0 SPACING 3 * ROT []FILL BECOMES> CV.DIST
TEGER DIM[ DIM1 10 + ] UNNAMED.ARRAY DUP
      0 SPACING 3 * 10 + ROT []FILL BECOMES> AVG.DIST
 REAL DIM[ DIM1 ] UNNAMED.ARRAY
      0 OVER := DUP DUP DUP DUP 4 *DUP
      BECOMES> BOOM1  BECOMES> BOOM2  BECOMES> NOZ1
      BECOMES> NOZ2   BECOMES> NOZ3   BECOMES> NOZ4
      BECOMES> NOZ0   BECOMES> NOZ5
 REAL DIM[ DIM1 10 + ] UNNAMED.ARRAY
      0 OVER := DUP DUP
      BECOMES> AVG.WT1  BECOMES> AVG.WT2

IALS 0 >

CREEN.CLEAR CR ." SIMULATING SPRAY BOOM FOR NEW NOZZLE..."
 84 42 DO                \ 84 BECAUSE 1 MORE THAN NEEDED IS REQUIRED
                         \ FOR THE DO LOOP
     ELEM0 I + 1 >=
     ELEM0 I + DIM1 <= AND
     IF
      sm.wt1 [ I ] NOZ0 [ ELEM0 I + ] :=
     THEN
     I 41 - DIM1 <=
     IF
      sm.wt1 [ I ] NOZ1 [ I 41 - ] :=
     THEN
 LOOP
 84 1 DO
     ELEM1 I + 1 >=
     ELEM1 I + DIM1 <= AND
     IF
      sm.wt1 [ I ] NOZ2 [ ELEM1 I + ] :=
     THEN
```

```
      ELEM2 I + 1 >=
      ELEM2 I + DIM1 <= AND
      IF
       sm.wt1 [ I ] NOZ3 [ ELEM2 I + ] :=
      THEN
  LOOP
  43 1 DO
      ELEM3 I + 1 >=
      ELEM3 I + DIM1 <= AND
      IF
       sm.wt1 [ I ] NOZ4 [ ELEM3 I + ] :=
      THEN
      ELEM4 I + 1 >=
      ELEM4 I + DIM1 <= AND
      IF
       sm.wt1 [ I ] NOZ5 [ ELEM4 I + ] :=
      THEN
  LOOP

  NOZ0 NOZ1 + NOZ2 + NOZ3 + NOZ4 + NOZ5 + BOOM1 :=
  BOOM1 SAMPLE.VARIANCE SQRT ST.DEV1 :=
  BOOM1 MEAN AVG1 :=
  ST.DEV1 AVG1 / 100 * CV1 :=
N



.V.2
IALS 0 )

TACK.CLEAR
   0 NOZ0 := 0 NOZ1 :=  0 NOZ2 :=  0 NOZ3 :=  0 NOZ4 :=  0 NOZ5 :=
CREEN.CLEAR CR ." SIMULATING SPRAY BOOM FOR WORN NOZZLE..."
 84 42 DO                 \ 84 BECAUSE 1 MORE THAN NEEDED IS REQUIRED
                          \ FOR THE DO LOOP
      ELEM0 I + 1 >=
      ELEM0 I + DIM1 <= AND
      IF
       sm.wt2 [ I ] NOZ0 [ ELEM0 I + ] :=
      THEN
      I 41 - DIM1 <=
      IF
       sm.wt2 [ I ] NOZ1 [ I 41 - ] :=
      THEN
  LOOP
  84 1 DO
      ELEM1 I + 1 >=
      ELEM1 I + DIM1 <= AND
      IF
       sm.wt2 [ I ] NOZ2 [ ELEM1 I + ] :=
      THEN
      ELEM2 I + 1 >=
      ELEM2 I + DIM1 <= AND
      IF
```

```
        sm.wt2 [ I ] NOZ3 [ ELEM2 I + ] :=
      THEN
 LOOP
 43 1 DO
      ELEM3 I + 1 >=
      ELEM3 I + DIM1 <= AND
      IF
        sm.wt2 [ I ] NOZ4 [ ELEM3 I + ] :=
      THEN
      ELEM4 I + 1 >=
      ELEM4 I + DIM1 <= AND
      IF
        sm.wt2 [ I ] NOZ5 [ ELEM4 I + ] :=
      THEN
 LOOP

 NOZ0 NOZ1 + NOZ2 + NOZ3 + NOZ4 + NOZ5 + BOOM2 :=
 BOOM2 SAMPLE.VARIANCE SQRT ST.DEV2 :=
 BOOM2 MEAN AVG2 :=
 ST.DEV2 AVG2 / 100 * CV2 :=
N


IS.DEFAULTS                           \ RESET THE DEFAULT PARAMETERS

RAPH3
=.VUPORT NORMAL.COORDS
IALS 0 >

 .0025 .0 .0025 DASHED
3IT1
,WT2
.AUTO.PLOT
N
_ID
3IT1
.WT1
IALS 0 >  NTRIALS 0 >  AND
 XY.DATA.PLOT  THEN
IALS 0 >  WTRIALS 0 <=  AND
 XY.AUTO.PLOT  THEN
RMAL.COORDS
16667 .033333 CHAR.SIZE
 LABEL.DIR
 CHAR.DIR
7 .5 POSITION  " WEIGHT (grams)" CENTERED.LABEL
_ABEL.DIR
CHAR.DIR
 .068 POSITION " DISTANCE (cm)" CENTERED.LABEL
3 .95 POSITION " SPRAY NOZZLE" CENTERED.LABEL CR
3 .88 POSITION " DISTRIBUTION" CENTERED.LABEL CR
1 .03 CHAR.SIZE
 .91 POSITION NOZZLE_TYPE LABEL
 .95 POSITION NOZZLE_GPM LABEL


ST Version 3.10
e 17    SUPER2.   02/17/92   21:42:00.41
```

```
 .8 KEY.ORIG
2 KEY.SIZE
 .0025 .0 .0025 DASHED  " WORN" 0 KEY.LINE
_ID  "  NEW" 1 KEY.LINE
Y.DONE
53 .95 POSITION "  NEW AVG. %ERROR=" LABEL
53 .914 POSITION " WORN AVG. %ERROR=" LABEL
5 .95 POSITION ERROR1L LABEL
5 .914 POSITION ERROR2L LABEL
<EY DROP ?DROP


_OT3
REEN.CLEAR
 CR CR CR CR CR CR ."                                PLOTTING..."
7470
DTTER.DEFAULTS                              \ RESET THE DEFAULT PARAMETERS
APH3
M.GRAPHICS
VICE.INIT


RAPH4
AB1 [ 1 ] :=   250 AB1 [ 2 ] :=
F.VUPORT NORMAL.COORDS      \ RESET THE DEFAULT PARAMETERS
 ." Do you want the C.V. graph on AUTO or FIXED scaling?"
 ."       (A)uto            or            (F)ixed"
 "INPUT SCALING ":=
ALING " F" "=
ALING " f" "= OR

  2 COLOR
  " ." SYMBOL
  AB1
  AB2
  " F" SCALING ":=
  XY.AUTO.PLOT
EN
COLOR
IALS 0 )

 .0025 .0 .0025 DASHED
.DIST
OM2
ALING " F" "=

  XY.DATA.PLOT
EN
ALING " A" "=
ALING " a" "= OR

  XY.AUTO.PLOT
  " A" SCALING ":=
EN


ST Version 3.10
e 18    SUPER2.   02/17/92   21:42:02.23
```

```
N
IALS 0 )

_ID
.DIST
OM1
ALING " F" "=

  XY.DATA.PLOT
EN
ALING " A" "=

  XY.AUTO.PLOT
EN
N
IALS 0 )

05 .0025 .005 .0025 DASHED
G.DIST
G.WT1
.DATA.PLOT
N
IALS 0 )

1 .0025 .01 .0025 DASHED
G.DIST
G.WT2
.DATA.PLOT
N
_ID
16667 .033333 CHAR.SIZE
 LABEL.DIR
 CHAR.DIR
RMAL.COORDS
7 .5 POSITION  " WEIGHT (grams)" CENTERED.LABEL
LABEL.DIR
CHAR.DIR
 .085 POSITION " DISTANCE (cm)" CENTERED.LABEL
63 .95 POSITION " WORN %CV=" LABEL  .163 .914 POSITION "  NEW %CV=" LABEL
19 .95 POSITION CV2L LABEL   .319 .914 POSITION CV1L LABEL
76 .95 POSITION " WORN S.D=" LABEL  .476 .914  POSITION "  NEW S.D=" LABEL
32 .95 POSITION SD2L LABEL   .632 .914 POSITION SD1L LABEL
1 .03 CHAR.SIZE
 .745 KEY.ORIG
4 KEY.SIZE
 .0025 .0 .0025 DASHED  " WORN" 0 KEY.LINE
LID  "  NEW" 1 KEY.LINE
1 .0025 .01 .0025 DASHED " WORN MEAN" 2 KEY.LINE
05 .0025 .005 .0025 DASHED "  NEW MEAN" 3 KEY.LINE
Y.DONE
 .91 POSITION NOZZLE_TYPE LABEL
 .95 POSITION NOZZLE_GPM LABEL
7 .02 POSITION AVG1L LABEL
7 .05 POSITION AVG2L LABEL


ST Version 3.10
e 19    SUPER2.   02/17/92   21:42:04.26
```

```
3 .02 POSITION "  NEW MEAN=" LABEL
3 .05 POSITION " WORN MEAN=" LABEL
 .02 POSITION " NOZZLE SPACING =" CENTERED.LABEL
 .02 POSITION SPACINGL LABEL    .65 .02 POSITION " (cm)" LABEL
KEY DROP ?DROP


LOT4
REEN.CLEAR
 CR CR CR CR CR CR ."                                PLOTTING..."
7470
OTTER.DEFAULTS                          \ RESET THE DEFAULT PARAMETERS
F.VUPORT NORMAL.COORDS
APH4
M.GRAPHICS


\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\

TART
IN
2
PNS 2 =

  GO
EN
PNS 3 <>

 N" ANS ":=
SPNS 1 =
F
SCREEN.CLEAR
CR ." Has this data already been sorted, averaged, AND smoothed?"
CR ."              (Y)es or (N)o"  CR
"INPUT ANS ":=
" Y" ANS "=  " y" ANS "=  OR
IF
  WEIGHT1 sm.wt1 :=
  WEIGHT2 sm.wt2 :=
THEN
HEN
 n" ANS "=
 N" ANS "= OR
F
SORTER
AVRG
AVGD.WT1 SMD.WT1 :=                    \  IN CASE SMOOTHING IS NOT DONE
AVGD.WT2 SMD.WT2 :=                    \  THE ARRAYS SMD.WT1 & 2 MUST EXIST
SMOOTHER                                           \ SMOOTHING
XCHG2
HEN
EN

GIN


ST Version 3.10
e 20    SUPER2.   02/17/92   21:42:06.24
```

```
.V.1
.V.2
VG1 AVG.WT1 :=
VG2 AVG.WT2 :=
V1 -1 2 FIX.FORMAT "." CV1L ":=
V2 -1 2 FIX.FORMAT "." CV2L ":=
T.DEV1 -1 4 FIX.FORMAT "." SD1L ":=
T.DEV2 -1 4 FIX.FORMAT "." SD2L ":=
VG1 -1 3 FIX.FORMAT "." AVG1L ":=
VG2 -1 3 FIX.FORMAT "." AVG2L ":=
RROR1S -1 2 FIX.FORMAT "." ERROR1L ":=
RROR2S -1 2 FIX.FORMAT "." ERROR2L ":=
PACING -1 0 FIX.FORMAT "." SPACINGL ":=
1 4 FIX.FORMAT
TRIALS WTRIALS + 2 + ITER :=

CREEN.CLEAR
R ." Do you want to save this sorted, averaged, & smoothed"
R ." data for ALL trials combined of both new & worn nozzles?"
R ."                  (Y)es or (N)o "  CR
INPUT ANS ":=
 Y" ANS "=
 y" ANS "= OR
F
\ ***********FINAL SAVE OF OVERALL NEW NOZZLE DATA***********
84 COUNT :=                         \ 84 IS NEEDED FOR PROGRAM EXECUTION
                                    \ WHEN FILE IS CALLED BACK IN TO SUPER.
REAL  dim[ 83 ]  UNNAMED.array
0 over := BECOMES> WT2
INTEGER  dim[ 83 ]  UNNAMED.array
0 over := BECOMES> DIST2
REAL  dim[ 84 ]  UNNAMED.array
0 over := BECOMES> WT
INTEGER  dim[ 84 ]  UNNAMED.array
0 over := BECOMES> DIST1
-41 42 DIST1 []FILL

IALS 0 >

SCREEN.CLEAR
." ENTER FILENAME & COMMENT FOR NEW NOZZLE!"
GET.FILENAME&COMMENT

SMD.WT1 WT :=
POSIT1 DIST2 :=
sm.wt1 WT2 :=
AVG1 AVG :=
ST.DEV1 ST.DEV :=
CV1 CV :=
ERROR1S ERR :=

CR ." CHOOSE (1) OR (2)."
CR SAVE.OR.EXIT?
N


ST Version 3.10
e 21    SUPER2.   02/17/92   21:42:08.76
```

```
IALS 0 )

\ ***********FINAL SAVE OF OVERALL WORN NOZZLE DATA***********
CR CR CR ." ENTER FILENAME & COMMENT FOR WORN NOZZLE!"
GET.FILENAME&COMMENT

REAL  dim[ 83 ]  UNNAMED.array
0 over := BECOMES> WT2
INTEGER  dim[ 83 ]  UNNAMED.array
0 over := BECOMES> DIST2
REAL  dim[ 84 ] UNNAMED.array
0 over := BECOMES> WT

SMD.WT2 WT :=
POSIT1 DIST2 :=
sm.wt2 WT2 :=
AVG2 AVG :=
ST.DEV2 ST.DEV :=
CV2 CV :=
ERROR2S ERR :=

CR ." CHOOSE (1) OR (2)."
CR SAVE.OR.EXIT?
HEN
N
 \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\GRAPH & PLOT !!!!
EGIN
  SCREEN.CLEAR
  CR ." Enter nozzle material: "
  CR ."      1) NYLON "
  CR ."      2) PLASTIC "
  CR ."      3) HARD. STAIN. STEEL "
  CR ."      4) STAINLESS STEEL "
  CR ."      5) BRASS "   CR
  "INPUT ANS ":=
  ANS " 1" "=       ANS " N" "= OR   ANS " n" "= OR
  ANS " 2" "= OR    ANS " P" "= OR   ANS " p" "= OR
  ANS " 3" "= OR    ANS " H" "= OR   ANS " h" "= OR
  ANS " 4" "= OR    ANS " S" "= OR   ANS " s" "= OR
  ANS " 5" "= OR    ANS " B" "= OR   ANS " b" "= OR
NTIL
  ANS " 1" "=   ANS " N" "= OR   ANS " n" "= OR
  IF  " NYLON" NOZZLE_TYPE ":=                 THEN
  ANS " 2" "=   ANS " P" "= OR   ANS " p" "= OR
  IF  " PLASTIC" NOZZLE_TYPE ":=               THEN
  ANS " 3" "=   ANS " H" "= OR   ANS " h" "= OR
  IF  " HARD. STAIN. STEEL" NOZZLE_TYPE ":=    THEN
  ANS " 4" "=   ANS " S" "= OR   ANS " s" "= OR
  IF  " STAINLESS STEEL" NOZZLE_TYPE ":=       THEN
  ANS " 5" "=   ANS " B" "= OR   ANS " b" "= OR
  IF  " BRASS" NOZZLE_TYPE ":=                 THEN

EGIN
 SCREEN.CLEAR


ST Version 3.10
e 22    SUPER2.   02/17/92   21:42:11.56
```

```
 CR ." Enter the nozzle capacity in gpm:"
 CR ."       2) 0.2 gpm "
 CR ."       4) 0.4 gpm "
 CR ."       6) 0.6 gpm "
 CR ."       8) 0.8 gpm "   CR
 #INPUT NOZZLE_GPM# :=
 NOZZLE_GPM# 2 =  NOZZLE_GPM# 4 = OR  NOZZLE_GPM# 6 = OR
 NOZZLE_GPM# 8 =  OR
NTIL
DZZLE_GPM# 2 =
F
 " 0.2 gpm (0.8 Lpm)" NOZZLE_GPM ":=
 1.25 AB2 [ 1 ] :=   0. AB2 [ 2 ] :=
HEN
DZZLE_GPM# 4 =
F
 " 0.4 gpm (1.5 Lpm)" NOZZLE_GPM ":=
 2.5 AB2 [ 1 ] :=   0. AB2 [ 2 ] :=
HEN
DZZLE_GPM# 6 =
F
 " 0.6 gpm (2.3 Lpm)" NOZZLE_GPM ":=
 4.0 AB2 [ 1 ] :=   0. AB2 [ 2 ] :=
HEN
DZZLE_GPM# 8 =
F
 " 0.8 gpm (3.0 Lpm)" NOZZLE_GPM ":=
 6.0 AB2 [ 1 ] :=   0. AB2 [ 2 ] :=
HEN

TACK.CLEAR
PPLOTTER                          \ MAKE HPPLOTTER CURRENT RS232 DEVICE
XIS.DEFAULTS
RAPH3
R CR CR CR
R ." Do you want to plot this graph?"
R ."       (Y)es or (N)o           "
INPUT ANS ":=
 Y" ANS "=
 y" ANS "= OR
F                                   \ PLOT IF USER ANSWERS YES
CR CR CR CR
CR ." Change the RS232 cable so that the plotter is hooked"
CR ." up to the computer (not the balance). Then press <CR>."
PCKEY DROP ?DROP
PLOT3
HEN
XIS.DEFAULTS
RAPH4
R CR CR CR
R ." Do you want to plot this graph?"
R ."       (Y)es or (N)o           "
INPUT ANS ":=
 Y" ANS "=
```

'ST Version 3.10
e 23   SUPER2.   02/17/92   21:42:14.04

```
 y" ANS "= OR
=                                          \ PLOT IF USER ANSWERS YES
CR CR CR CR
CR ." Change the RS232 cable so that the plotter is hooked"
CR ." up to the computer (not the balance). Then press (CR)."
PCKEY DROP ?DROP
PLOT4
HEN
ORMAL.DISPLAY
ALANCE

CREEN.CLEAR
R ." DO YOU WISH TO:  (1) CONTINUE with another set of nozzles      OR"
R ."                  (2) CONTINUE with a different nozzle spacing  OR"
R ."                  (3) EXIT the program ?"
R #INPUT ANSWER2 :=
ACK.CLEAR
ANSWER2 <>
TIL
NSWER2 =
IL


O.ON CR
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
    ASYST PROGRAM SUPER. IS DESIGNED FOR USE WITH AN AUTOMATED SPRAY
 PATTERN DISTRIBUTION TABLE OR DATA COLLECTED FROM NOZZLE SPRAY PATTERN
 TESTING.
    IF YOU ARE RUNNING TESTS:
 SET THE BALANCE SO THAT THE LEFT SIDE OF THE HOUSING IS EVEN WITH
 THE LEFT UPRIGHT PIECE OF THE FRAME, IE. SO THAT THE POSITION SENSOR'S
 CABLE IS EXTENDED APPROXIMATELY 10 CM OR 4 INCHES.  THIS IS THE POSITION
 AT WHICH THE BALANCE SHOULD BE TARED.
    THE BALANCE MAY BE MOVED AT ANY CONSTANT SPEED AND MAY BE STARTED ANY
 TIME AFTER THE PROGRAM TARES IT.
 THE BALANCE SHOULD BE STOPPED ONCE THE RIGHT SIDE OF THE HOUSING IS ABOUT
 EVEN WITH THE RIGHT UPRIGHT PIECE OF THE FRAME, IE. ABOUT 14 CM OR 5 1/2
 INCHES FROM THE END OF THE DOUBLE BAR TRACK.
    THIS PROGRAM MAY ALSO BE USED TO MANIPULATE EXISTING DATA FOR DIFFERENT
 NOZZLE SPACINGS.  % C.V.'S, AVERAGES, AND STANDARD DEVIATIONS ARE COMPUTED
 FOR A SIMULATED SPRAY BOOM WITH THE GIVEN NOZZLE SPACING.

 YOU WILL HAVE A CHANCE TO STORE THE DATA IN A LOTUS 123 FORMAT AT THE END.
                        ****  TYPE START TO BEGIN  ****
\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
HO.OFF
```

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